2010

Society for Mathematical Psychology

43rd Annual Conference
Portland, OR

Program & Information

Welcome

Welcome to MP2010, the 43rd annual meeting of the *Society for Mathematical Psychology*, being held in the Embassy Suites Portland in Downtown Portland.

This year's conference features plenary addresses from Mike Jordan, Larry Maloney, and William K. Estes Early Career Award winner Thomas Griffiths. There are 4 invited symposia, 122 accepted talks and 22 poster presentations.

Registration

You can register from 6pm–9pm in the Colonel Lindbergh room (overlapping with the reception from 7pm–9pm), or during the conference.

You will receive a printed copy of this program, including the abstracts and schedule, as well as your name tag, which is stamped to indicate banquet purchases.

Conference Events

Reception

The reception is Saturday evening, from 7pm–9pm in the Colonel Lindbergh room, overlapping with registration. There will be a cash bar.

Business Meeting

The business meeting will be held from 5pm Monday, in a location to be announced.

Conference Banquet

The conference dinner will be Monday from 7pm–10pm in the Queen Marie Ballroom. Tickets for the banquet need to pre-purchased.

Lunch

Morning & afternoon coffee breaks are provided during the conference, but lunch is on your own.

Program Booklet Credits

LaTeX-code generation, lay-out, cover:	Timo Kluck, Infty Advies (www.infty.nl) with MLC, inc.

Presentation Guidelines

Talks

Talks will be held in three parallel sessions, in the Gevurtz, Fireside and Queen Marie room. Please see the schedule at the end of this program. Presentation time will be limited to a total of 20 minutes, which includes five minutes for discussion. Talks will be strictly timed, and synchronized across sessions.

We ask the *last presenter* in each session to keep time (since they are the person most motivated to keep to the schedule!), and arrange a time-keeper for their own talk.

Posters

The poster session will be held Sunday from 5pm–6.30pm in the Colonel Lindbergh room. The poster boards are 8' wide by 4' tall.

Acknowledgments

Sponsors

We are grateful to the **Air Force Office of Scientific Research (AFOSR)**, and the **National Science Foundation (NSF)** for their generous financial support for the conference.

We also thank the **Cognitive Science Society** for sponsoring the prize for the best student poster on a cognitive modeling topic.

People

Conference Chair: **Robin Thomas**
Local Organizer: **Misha Pavel**, **Sandy Baxter**
Financial Chair: **Rich Golden**
Academic Program : **Michael Lee**
Webmaster: **Annemarie Zand Scholten**
Website 2010: **James Pooley**
Registration: **Jenny Shi**, **Daniela Amado**
Business Consultant: **Pernille Hemmer**

Abstracts

INVITED PLENARY TALKS

Sunday, 13:45 (Session B)

Movement Planning under Risk, Decision Making under Risk. Larry Maloney *NYU* . In executing any speeded movement, there is uncertainty about the outcome due to motor variability. I'll describe recent experiments in which subjects carried out speeded motor tasks that were equivalent to economic decisions. The outcome of each movement earned an explicit monetary reward or penalty. In one game, for example, subjects attempted to reach out and touch briefly presented reward disks while avoiding nearby, overlapping penalty disks. The task for the subject was to trade off the risk of missing the reward disk against the risk of hitting the penalty disk. The optimum tradeoff depended on the magnitudes of penalty and reward and the subject's own motor error. For each subject, in each game, we could estimate the ideal movement strategy and maximum expected gain possible. We compared subjects' movements and winnings to this ideal. In many of these experiments, subjects consistently chose movements that were close to optimal. This outcome is surprising: these motor tasks are, after all, formally equivalent to decision making under risk and subjects making decisions under risk typically do not maximize expected gain. I'll describe very recent work in which we set out to translate classical decision making experiments (concerning the independence axiom of expected utility theory) into motor form and compare decision making under risk to movement planning under risk in the same subjects.

Monday, 13:45 (Session B)

Recent Developments in Nonparametric Bayesian Inference. Mike Jordan *UC Berkeley* . Bayesian inference is often viewed as an assumption-laden approach to statistical inference, whereby strong assumptions about existing knowledge are imposed in order to support the acquisition of new knowledge from data. The past two decades have seen the development of an increasingly vigorous field of Bayesian nonparametrics, which simultaneously provides a more expressive language for prior knowledge and allows for weaker specifications. Mathematically, Bayesian nonparametrics amounts to using general stochastic processes as prior distributions. I discuss a class of stochastic processes known as "completely random measures" that I view as providing particularly useful building blocks for Bayesian nonparametrics. I will discuss applications of models based on completely random measures to several problem domains, including natural language processing, protein structural modeling, computational vision, and statistical genetics.

Tuesday, 13:45 (Session B)

Using Probabilistic Models of Cognition to Identify Human inductive Biases. Thomas Griffiths *UC Berkeley* . People are remarkably good at acquiring complex knowledge from limited data, as is required in learning causal relationships, categories, or aspects of language. Successfully solving inductive problems of this kind requires having good "inductive biases" – constraints that guide inductive inference. Viewed abstractly, understanding human learning requires identifying these inductive biases and exploring their origins. I will argue that probabilistic models of cognition provide a framework that can facilitate this project, giving a transparent characterization of the inductive biases of ideal learners. I will discuss three ways in which these models can be used to shed

light on human inductive biases: comparing predictions, assessing learnability, and designing experimental methods that magnify the effects of inductive biases.

INVITED SYMPOSIA

New computational approaches to word learning. (Organizer: Amy Perfors)

Tuesday, 9:00 (Session A)

New computational approaches to word learning. Luke Maurits, Amy Perfors, Daniel Navarro, *University of Adelaide* . All language learners must face the task of inferring the mappings between words and their referents. Similarly, learning which word orders are permitted in one's language is one of the first grammatical learning tasks those same learners must solve. We present modelling results suggesting that: 1) word order distributions across languages may reflect an optimal response to the computational problem of conveying information over a noisy channel, as the Uniform Information Density (UID) hypothesis suggests; and 2) learning is improved when word order and word reference are acquired jointly.

Tuesday, 9:20 (Session A)

Learning Word Meanings from Sequential and Syntactic Statistics. Mark Andrews, *NTU and UCL*, Gabriella Vigliocco, *UCL* . A promising recent approach to the problem of the learning and representation of word-meaning takes as its starting point the hypothesis that nontrivial aspects of the meaning of words can be inferred from their statistical distribution across spoken and written language. Numerous large-scale computational implementations have successfully demonstrated the validity of this so-called distributional hypothesis. Important as these computational models have been, one of their widely shared practices has been to treat the linguistic contexts in which a word occurs as unordered sets of words. By disregarding all fine-grained sequential and syntactic information, however, these models drastically restrict the information from which word meanings can be learned. All languages have strong syntactic-semantic correlations. The sequential order in which words occur, the argument structure and general syntactic relationships within sentences, all provide vital information about the possible meaning of words. In this work, we will describe a set of Bayesian distributional models that go beyond the "bag-of-words" paradigm. These models provide a framework to address how semantic representations can be learned from coarse and fine-grained distributional statistics, including those provided by sequential and syntactic information. They also allow us to address the key issue of how polysemous words are represented and learned. In particular, we will address how distributional models that incorporate sequential and syntactic information explain how these continua of senses can be learned and disambiguated.

Tuesday, 9:40 (Session A)

Beyond Boolean Logic: A learning theory for complex compositional concepts. Steven Piantadosi, Joshua Tenenbaum, Noah Goodman, *MIT* . We study the learning of novel words which express set-theoretical concepts often found in the functions words of natural language. We first present an experiment in which subjects inferred the meanings of a word which denoted an abstract concept that could only be expressed in a rich representational system. These concepts referred to properties of objects in sets, including Boolean expressions of features (e.g., "red or circle"), context-sensitive concepts (e.g., "the largest in the set"), and concepts requiring quantification (e.g., "every shape such that there is another shape of the same color in the set"). We show that subjects are capable of easily inferring many of these concepts, often learning abstract, context-dependent rules that involve explicit use of set-theoretic and quantificational operations. We then present a computational model which is similarly capable of learning these concepts and provides a good fit to human learning curves. The computational model formalizes probabilistic inference over a structured representation language for expressing possible meanings. We compare the perfor-

mance of several representation languages in predicting the human generalizations and show that people's patterns of induction require a language capable of set-theoretic, and quantificational operations. This work extends classical rule-based concept learning studies to representational systems of sufficient formal power to represent compositional linguistic meanings, and provides an explicit computational theory for how children may learn words that perform abstract semantic functions.

Tuesday, 10:00 (Session A)

One-Shot Learning with a Hierarchical Nonparametric Bayesian Model. Ruslan Salakhutdinov, Joshua Tenenbaum, Antonio Torralba, *MIT* . In typical applications of machine classification algorithms, learning curves are measured in tens, hundreds or thousands of training examples. For humans learners, however, the most interesting regime occurs when the training data are very sparse. Just a single example of a novel category is often sufficient for people to grasp a concept and make meaningful generalizations to novel instances. In this talk we will present a nonparametric hierarchical Bayesian model that aims to capture this human-like pattern of one-shot learning. The proposed model leverages higher-order knowledge abstracted from previously learned categories to estimate the new category's prototype as well as an appropriate similarity metric from just one example. We provide an efficient MCMC algorithm and show on several real-world datasets that the model is able to learn useful representations of novel categories based on a single training example.

Tuesday, 10:50 (Session A)

Early word learning through communicative inference. Michael Frank, *Stanford University* . How do children learn their first words? While they are able to make use of distributional information about the co-occurrence of words and objects, even very young children also seem to take into account information about speakers' communicative intentions. Rather than being though of as purely statistical or purely social, I argue that children's early word learning is best modeled as a process of statistical inference about speakers' communicative intentions. In this talk I will describe a Bayesian model of word learning based on this idea. The model takes as its input coded corpus data from mother-child interactions and makes joint inferences about what is being talked about (the mother's intended referent) and the lexicon of the language being used. Making these joint inferences allows the model to achieve considerably higher performance than comparable associative models (which do not make any assumptions about the speaker's intentions) even without including additional information. I will also describe ongoing work on including cues such as eye-gaze and pointing into the model. In addition to performing better in learning from corpus data, our model allows us to make novel developmental predictions about the phenomenon of disambiguation (mutual exclusivity). We test some of these predictions with adults and children and find that our data support a probabilistic view of mutual exclusivity but are not consistent with either pragmatic or lexical principles approaches.

Tuesday, 11:10 (Session A)

Using a developing lexicon to constrain phonetic category acquisition. Naomi Feldman, *Brown University*, Thomas Griffiths, *University of California, Berkeley*, Sharon Goldwater, *University of Edinburgh*, James Morgan, *Brown University* . Infants begin segmenting and categorizing words as early as 6 months, mapping tokens heard in isolation onto tokens of the same word heard in fluent sentences, and this ability continues to develop over the next several months (Bortfeld et al., 2005; Jusczyk & Aslin, 1995; Jusczyk et al., 1999). During the same time period, they show evidence of learning native language phonetic categories (Werker & Tees, 1984). We use a hierarchical Bayesian model to explore how building a rudimentary lexicon can help a learner acquire phonetic categories more robustly. The model learns to categorize speech sounds and words simultaneously from a corpus of segmented acoustic tokens. No lexical

information is given to the model a priori; it is simply allowed to begin learning a set of word types at the same time that it learns to categorize speech sounds. Simulations compare this model to a purely distributional learner that does not have feedback from a developing lexicon (McMurray et al., 2009; Vallabha et al., 2007). The models are tested on a corpus constructed from CHILDES frequency data (Li & Shirai, 2000; MacWhinney, 2000) and English vowel production data (Hillenbrand et al., 1995), and results show that whereas a distributional learner mistakenly merges several sets of overlapping categories, an interactive model successfully disambiguates these categories. This provides one example of how feedback from a developing lexicon can potentially improve learning in other domains, helping make the learning problem more tractable.

Models of episodic memory. (Organizer: Simon Dennis)

Monday, 9:00 (Session A)

Learning to Forget: An Interference Account of Cue-Independent Forgetting. Tracy Tomlinson, *University of Maryland, College Park*, David Huber, *University of California, San Diego* . In memory inhibition theory, forgetting is intentional, serving to eliminate unwanted or distracting memories. The signature of memory inhibition is cue-independent forgetting in which a target memory is not recalled even in response to an episodically unrelated semantic cue. In contrast, forgetting is due to interference in global matching memory models. We demonstrate that these models can explain cue-independent forgetting if there is interference within the recovery stage of retrieval. A byproduct of learning to forget is that a sampled (not yet recovered) memory is now associated with some alternative response, which explains why a deficit can exist regardless of the cues used to probe memory. We report 2 experiments that tested this account. The first experiment used the think/no-think paradigm, revealing 1) similar forgetting when people are instead trained to press enter; 2) greater forgetting for initially weak memories; and 3) these effects exist for recall but not recognition. The second experiment tested recovery interference by using a semantic cue to train recovery of a competing response. As predicted, this produced a memory deficit even though the original target was not referenced by this training.

Monday, 9:20 (Session A)

A REM model of retrieval-induced forgetting. Eddy Davelaar, *Birkbeck, University of London* . The retrieval-induced forgetting paradigm consists of three phases. In phase 1, participants study a number of category-exemplar pairs in sequence. Typically, each category label is paired six exemplars. In phase 2, half of the presented category labels are presented as a cue together with some letters of the target exemplar. The participants task is to retrieve the target exemplar. However, only half of the exemplars that were paired with the category label are retrieved, creating two experimental conditions: non-retrieved items (Rp-) and retrieved items (Rp+). In the third phase, all exemplars are probed and the memory tested. Comparing the non-practiced items (Nrp) against Rp+ shows the basic learning effect, whereas comparing them against Rp- shows a disadvantage for the Rp- items. This behavioural inhibition has been discussed in the literature as evidence for a mechanistic inhibition, i.e., memories are permanently erased. The alternative view is that the performance difference is due to interference. This debate is played out using recall data. The interesting point here is that the strongest argument fro an inhibition account is the presence of below-baseline performance in recognition memory. In this talk, I will present a REM-based model of retrieval-induced forgetting that captures the recognition data. The choice for REM in this simulation study is that REM is an interference-based model. By showing its capability of capturing retrieval-induced forgetting in item recognition, the view of mechanistic inhibition is further questioned. The simulation study also shows the benefit of modelling in interpreting "inhibition" findings.

Monday, 9:40 (Session A)

Using cued recall to move beyond task specific models. Amy Criss, William Aue, *Syracuse University* . Free recall and single item recognition have been extensively studied from an empirical and modeling framework. A number of variables have different effects on performance in these two tasks. These dissociations have inspired and informed theory development, but they have also contributed to development of models devoted to accounting for performance in just one task and neglecting the other task. Cued recall shares properties with single item recognition and free recall, making it a candidate task to resolve dissociations between the two tasks and connect these two fields. The independent effects of word frequency and context variability on cues and targets are evaluated in a series of experiments. Implications for current models of memory and the prospects of future models are discussed.

Monday, 10:00 (Session A)

A distributed representation of remembered time. Marc Howard, Karthik Shankar, *Syracuse* . Episodic memory has been described by verbal theorists as a form of "mental time travel" in which the rememberer jumps back in time to partially relive a previous event. Distributed memory models (DMMs) have been applied to numerous episodic memory tasks, including item recognition, cued recall and free recall. We argue that while DMMs have provided a reasonable description of temporal effects in episodic memory, including recency and contiguity, thus far they have not incorporated a sufficiently detailed model of history to provide a satisfactory description of episodic memory. For instance, the temporal context model (TCM) models episodic memory as operations on a temporal context vector that changes during study and test. In TCM, the entire history with an item is thus expressed as a scalar value. Collapsing history in this way prevents a solution of some apparently basic phenomena in learning. We sketch a distributed representation of remembered time that can be constructed from a set of temporal context vectors with different time constants. In this model, the history with each item is expressed as a function of internal time. Recent events are expressed with greater precision than less recent events. In addition to a variety of timing behaviors, this model can account for recency and contiguity across time scales, as well as the activity of "time cells" observed in the rodent hippocampus. We discuss the potential for applications to a broad variety of other episodic memory tasks, including judgments of recency and frequency.

Monday, 10:50 (Session A)

The SARKAE model: Experience with novel characters determines recognition memory. Pt I. Angela Nelson, *UCSD*, Richard Shiffrin, *Indiana* . Episodic memory must involve storage in and retrieval from both general knowledge and event memory. Although experiments typically control event presentations, general knowledge is uncontrolled and highly variable across participants. We therefore trained knowledge for novel Chinese characters with training studies that continued for several weeks. Of particular interest was the role of character frequency: frequency varied geometrically across characters during training. Following this training, we gave tests of perception, knowledge retrieval, and episodic recognition memory. The recognition memory tests proved highly diagnostic for delimiting models. These talks describe the data from several studies, and the model they suggest for episodic recognition memory. Study one used a visual search task for training. High frequency characters tended to co-occur (as either targets or foils) across trials of training. The knowledge formation model we used stipulates that items thought about together (e.g. because they occurred in spatial/temporal proximity) tend to encode features from each other, in laying down both event traces and knowledge traces. Thus at the end of training higher frequency characters became more similar to each other in the knowledge base. Large frequency effects were observed in testing (and a mirror effect), but the roles of similarity and pure frequency were confounded in this study. Thus the second study trained knowledge about the Chinese characters in a way that would

not alter inter-character similarity: Each character had to be matched to itself, for a decision whether a slight physical alteration had occurred. Again frequency effects were observed in the post-training recognition task. We were led to an episodic recognition model in which summed familiarity (summed event trace activation) is used to make a recognition decision. Performance is degraded by two sources of noise: activation of traces of other characters in the study list, and activation of training traces of the test item. In study two (since similarity is equated across frequency) all frequency effects are produced by activation of training session traces. This model was tested in study two by a delayed recognition test given after six weeks post-training. Frequency effects tended to disappear, consistent with the model. The model had one more critical feature: Because study two revealed strong and persistent effects of frequency for pseudo-lexical decision, a role for pure frequency was required and incorporated in the model: Encoding of any presented character from knowledge was assumed to be more accurate for higher frequency characters. This factor has the effect of slightly improving episodic recognition accuracy for higher frequency characters, but the model nonetheless predicted both poorer overall recognition performance and faster overall pseudo-lexical decision latencies for higher frequency characters.

Monday, 11:10 (Session A)

The SARKAE model: Experience with novel characters determines recognition memory. Pt II. RICHARD SHIFFRIN, *Indiana*, ANGELA NELSON, *UCSD* . Episodic memory must involve storage in and retrieval from both general knowledge and event memory. Although experiments typically control event presentations, general knowledge is uncontrolled and highly variable across participants. We therefore trained knowledge for novel Chinese characters with training studies that continued for several weeks. Of particular interest was the role of character frequency: frequency varied geometrically across characters during training. Following this training, we gave tests of perception, knowledge retrieval, and episodic recognition memory. The recognition memory tests proved highly diagnostic for delimiting models. These talks describe the data from several studies, and the model they suggest for episodic recognition memory. Study one used a visual search task for training. High frequency characters tended to co-occur (as either targets or foils) across trials of training. The knowledge formation model we used stipulates that items thought about together (e.g. because they occurred in spatial/temporal proximity) tend to encode features from each other, in laying down both event traces and knowledge traces. Thus at the end of training higher frequency characters became more similar to each other in the knowledge base. Large frequency effects were observed in testing (and a mirror effect), but the roles of similarity and pure frequency were confounded in this study. Thus the second study trained knowledge about the Chinese characters in a way that would not alter inter-character similarity: Each character had to be matched to itself, for a decision whether a slight physical alteration had occurred. Again frequency effects were observed in the post-training recognition task. We were led to an episodic recognition model in which summed familiarity (summed event trace activation) is used to make a recognition decision. Performance is degraded by two sources of noise: activation of traces of other characters in the study list, and activation of training traces of the test item. In study two (since similarity is equated across frequency) all frequency effects are produced by activation of training session traces. This model was tested in study two by a delayed recognition test given after six weeks post-training. Frequency effects tended to disappear, consistent with the model. The model had one more critical feature: Because study two revealed strong and persistent effects of frequency for pseudo-lexical decision, a role for pure frequency was required and incorporated in the model: Encoding of any presented character from knowledge was assumed to be more accurate for higher frequency characters. This factor has the effect of slightly improving episodic recognition accuracy for higher frequency characters, but the model nonetheless

predicted both poorer overall recognition performance and faster overall pseudo-lexical decision latencies for higher frequency characters.

Monday, 11:30 (Session A)

Extending the Context Maintenance and Retrieval model of free recall. Sean Polyn, *Vanderbilt University*, Michael Kahana, *University of Pennsylvania* . The context maintenance and retrieval (CMR) model of memory search is a generalized version of the temporal context model of Howard and Kahana (2002). CMR proposes that memory search is driven by an internally maintained context representation composed of stimulus-related and source-related information. CMR suggests that organizational effects (the tendency for related items to cluster during the recall sequence) arise as a consequence of associations between active context elements and features of the studied material. The CMR model has been successful in accounting for organizational phenomena, as well as serial position effects and inter-response latencies, in both classic and new datasets (Polyn et al., 2009). An important avenue of development is to bring CMR into contact with other models of episodic memory. I will describe current work with the model in which we examine the tension between the predictions of context-based models such as CMR, and distinctiveness-based models such as SIMPLE (Brown et al., 2007). These recent investigations involve behavioral data from two new free recall studies, one examining the interaction between category information and temporal information, and the other examining a within-list manipulation of temporal isolation (as in Brown et al., 2006).

Monday, 11:50 (Session A)

What is context? Simon Dennis, Vishnu Sreekumar, Yuwen Zhuang, Mikhail Belkin, *Ohio State University* . Many of us purport to study episodic memory, which by definition is the ability to identify the occurrence of a stimulus in a specific context. Yet, outside the experimental setting, what constitutes a context is an elusive question. If one proposes that recognition memory is dominated by context noise, then this difficulty is compounded. To start to try to address the issue, we had subjects wear a Microsoft SenseCam^{TM}device that recorded images every 10-30 seconds over a period of a week. To understand the structure of their episodic experience, we analyzed the graph structure and dimensionality of these images. We show that these episodic graphs have a small-world structure which is characterized by sparse connectivity, short average path lengths, and high global clustering coefficients. The conjecture is that the temporally contiguous components of these clusters capture the external component of the notion of context. A degree distribution analysis shows that the graphs are not scale-free, however, a correlation dimension analysis shows they are close to having a single dimensionality across scales.

Practical applications of models for response time. (Organizer: Joachim Vandekerckhove)

Sunday, 9:00 (Session A)

A cognitive psychometrical model for speeded semantic categorization decisions. Joachim Vandekerckhove, Francis Tuerlinckx, Steven Verheyen, *University of Leuven* . Choice reaction times (RTs) are often used as a proxy measure of typicality in semantic categorization studies. However, other item properties have been linked to RTs as well. We apply a tailored process model of choice RT to a speeded semantic categorization task in order to deconfound different sources of variability in RT. Different aspects of the response process are then linked to different types of item properties. Typicality measures turn out to predict the rate of information uptake, while lexicographic measures predict the stimulus encoding time. Availability measures cannot predict any component of the decision process. Applying the diffusion model to the data at hand required its extension to a hierarchical Bayesian framework, so that a "crossed random effects diffusion model" could be constructed. This model retains the interesting process interpretation of the diffusion model's parameters, but it can be applied to choice reaction times even in the case where there are few

or no repeated measurements of each participant-item combination.

Sunday, 9:20 (Session A)

Modeling the Psychomotor Vigilance Test for Evaluating Sleep Deprivation. Roger Ratcliff, *The Ohio State University*, Hans van Dongen, *Washington State University* . I will present a model for the psychomotor vigilance test. This task has become a standard in assessing the behavioral effects of sleep deprivation. In the task, a millisecond timer remains off for between 2 and 10 seconds and then is turned on. The subject has to hit a button as soon as he/she detects that the counter is running. A critical finding is that when subjects are sleep deprived, they show lapses in performance, that is, produce long reaction times (RTs). The decision process used is a one boundary diffusion process (inverse Gaussian or Wald distribution of finishing times). This is preceded by a random Gaussian process that represents vigilance or readiness; it produces a delay prior to a signal to turn on the decision process. The model fits lapses (proportion of responses $>$ 500 ms say) and the RT distributions, including hazard functions. It fits these for sleep deprived and non-deprived sessions. The model parameters track alertness measures and they are correlated with parameters from fits to data collected at the same levels of deprivation from a two-choice numerosity discrimination task. I will also discuss application of the model to simple RT paradigms and relate the fits to two choice decisions.

Sunday, 9:40 (Session A)

Using the diffusion model to discriminate between memory models. Amy Criss, *Syracuse University* . In differentiation models, the processes of encoding and retrieval produce an increase in the distribution of memory strength for targets and a decrease in the distribution of memory strength for foils as the amount of encoding increases. This produces an increase in the hit rate and decrease in the false alarm rate for a strongly encoded compared to a weakly encoded list, consistent with empirical data. Other models assume that the foil distribution is unaffected by encoding manipulations or the foil distribution increases as a function of target strength. They account for the empirical data by adopting a stricter criterion for strongly encoded lists relative to weakly encoded lists. The differentiation and criterion shift explanations have been difficult to discriminate using accuracy measures. Reaction time distributions and accuracy measures are collected in a list strength paradigm and in a response bias paradigm where the proportion of test items that are targets was manipulated. Diffusion model analyses are used to discriminate between these memory model accounts.

Sunday, 10:00 (Session A)

Application of the Ratcliff Diffusion Model to Reaction Times in a Two-Choice Auditory Detection Task. Siu Lung Lo, Nicholas Huang, Laurel Carney, *University of Rochester*, Fabio Idrobo, *Boston University* . Abstract Amplitude modulations of acoustic stimuli are essential for carrying information in complex sounds and detection in noisy environments. We are studying the relationship between perception and physiology in response to amplitude modulations. Our purpose was to apply the Ratcliff Diffusion Model (RDM) to describe behavioral and physiological results in a study of detection of amplitude modulations of either tone or noise stimuli. This study involved a Bayesian tracking two-choice auditory detection task in which subjects (human and rabbit) were instructed to discriminate between modulated and unmodulated stimuli. Task difficulty (condition) was manipulated by systematically varying modulation in an effort to determine the detection threshold for amplitude modulation. Traditionally, studies of detection using two-choice procedures report only threshold estimates, and occasionally also report d' and bias. In this study the RDM was used to determine if these thresholds are percept driven, either by an accumulation of information or by other decision factors. Various nested RDMs that differed in parameter constraints were used to fit the reaction times using the DMAT toolbox. In general, the RDM model provided a good fit to the reaction time distributions. Across a range of

modulation frequencies, results showed that drift rate and probability of a modulated response increased with modulation depth, but they did not show evidence for a leading-edge effect, suggesting the need to consider physiological mechanisms that could yield categorical decisions in response to modulated sound. This RDM-based analysis enhances interpretation of the behavioral results and provides constraints for models of auditory processing.

Sunday, 10:50 (Session A)

Practice decomposed: stimulus specific versus task specific effects. Gilles Dutilh, Eric-Jan Wagenmakers, *University of Amsterdam*, Joachim Vandekerckhove, Francis Tuerlinckx, *Leuven University* . When people repeatedly practice the same cognitive task, their response times (RTs) invariably decrease. The mathematical function that best describes this decrease has been the subject of intense theoretical debate. Most theories of practice start from the assumption that the practice effect is driven by changes in a single psychological process. In our first study, we aimed to test this assumption of a unitary process, and to take into account the distribution of RTs and accuracy. Therefore, we set out to decompose the effect of practice with the Ratcliff diffusion model. A diffusion model analysis of data from a 10,000-trial lexical decision task demonstrates that practice not only affects speed of information processing, but also affects response caution, response bias, and peripheral processing time. In a second experiment, we aimed to further disentangle these effects into stimulus specific and task specific components. The data of this transfer experiment, in which repeatedly presented sets and new sets of stimuli were alternated, show that the practice effects on speed of information processing are largely stimulus specific. The effects of response caution and bias appear to be task specific. The effects on peripheral processes, however, are partly stimulus specific and partly task specific. We conclude that the diffusion model decomposition provides a perspective on practice that is more detailed and more informative than the traditional analysis of mean response times.

Sunday, 11:10 (Session A)

Combining fMRI and the LBA model to ascertain a supramodal accumulator in perceptual decision making. Tiffany Ho, *UCSD*, Scott Brown, *University of Newcastle, Australia*, John Serences, *UCSD* . Reaction time models have been successfully utilized in cognitive psychology as tools for describing and analyzing behavioral data. Far less common has been the use of RT models in brain data—specifically BOLD signals measured in fMRI. In this talk, I will describe a study that illustrates the efficacy of a RT model of behavior in analyzing fMRI data. Here, we used the linear ballistic accumulator (LBA) model (Brown and Heathcote, 2008) to ascertain supramodal decision making sites in the brain. Subjects participated in a perceptual decision making task which comprised of varying levels of difficulty and which required two different modes of response (saccades and button presses) while undergoing fMRI. Fits from our behavioral data were used to make predictions about BOLD responses for a supramodal evidence accumulator. Our analysis revealed that such an accumulator exhibits bigger and temporally extended BOLD responses characterized by a slower rise time on the relatively difficult trials. Based on this analysis, we were then able to identify the right insula as a candidate supramodal accumulator. By using a combination of RT models and fMRI, the mapping between model parameters (e.g., drift rate) and cognitive explanations (e.g., quality of sensory information extracted) can be made all the richer with the addition of a neural basis.

Sunday, 11:30 (Session A)

Developing and testing RT models for new paradigms. Corey White, Roger Ratcliff, *The Ohio State University* . We focus on one method to broaden the application of RT models, applying them to novel paradigms. Often this involves adjusting assumptions in the original models and incorporating constructs from domain-specific theories. We argue that any new version of an RT model should satisfy three main criteria. First, any addition assumptions or components that are added to the original

model should favor parsimony, both in number of parameters and psychological viability. Second, the newer model must be shown to adequately fit the relevant behavioral data, and the new model components should reflect the appropriate psychological constructs. Third, researchers must demonstrate that the additional assumptions or components do not adversely affect the original components of the model, and show that the standard model components still track the appropriate psychological constructs. We illustrate these principles with a comparison of diffusion models of the flanker task and identify a simple model that satisfies all three criteria, providing support for its use as an analytical tool.

Cognitive modeling and the wisdom of crowds. (Organizer: Mark Steyvers)

Sunday, 15:20 (Session A)
Cultural Consensus Theory. William Batchelder, *UCI* . Cultural consensus theory (CCT) is a formally based methodology for determining consensus answers to questions from groups of informants who share knowledge or beliefs. It was developed in the 1980s by myself, A. Kimball Romney, and colleagues, e.g. Batchelder & Romney (1988, *Psychometrika*); Romney, Weller, & Batchelder (1986, *American Anthropologist*), and since then CCT has become the leading methodology for determining consensus beliefs within the areas of cognitive anthropology, e.g. Weller (2007, *Field Methods*). CCT consists of a collection of cognitively motivated, parametric statistical models for aggregating the responses of informants to a series of test items about some domain of their shared knowledge or beliefs. It is based on a testable assumption that there are consensus (culturally correct) answers to the items based on the common culture of the informants; however, there is no requirement that the answers correspond to truths of the natural world. The models generally take the form of models in psychometric test theory except the correct answers are specified as parameters in the models rather than known apriori. In addition to estimating consensus answers, the models are used to estimate the cultural saliency of each item and the cultural competence and response bias characteristics of each informant. Thus far there are CCT models for true/false, multiple choice, digraph aggregation, matching tests, and continuous response tasks. The talk will describe some of the available models and application areas of CCT, and contrast it to other approaches to information aggregation.

Sunday, 15:40 (Session A)
Hierarchical models for improving individuals' subjective probabilities. Ed Merkle, *Wichita State University* . Common measures describing the "goodness" of subjective probabilities (e.g., those based on calibration and discrimination) fail to capture the full extent to which subjective probability and accuracy are related. A judge may exhibit poor calibration and discrimination, yet still report subjective probabilities that are predictive of accuracy. In the talk, I describe hierarchical models designed to exploit these relationships, transforming individuals' subjective probabilities without aggregating them. The resulting, transformed probabilities exhibit improved statistical properties that can also improve aggregation across individuals. Specific models studied within this framework include hierarchical logistic regression models and error models of confidence. The partial pooling inherent in the models implies that the crowd influences the way in which individuals' probabilities are transformed.

Sunday, 16:00 (Session A)
Wisdom of the Crowd Within: Sampling in Human Cognition. Ed Vul, *MIT* . Across a number of tasks, people approximate optimal Bayesian behavior, but exact Bayesian computations are impossible to carry out – how can cognition approximate ideal Bayesian inference despite limited cognitive resources? I argue that human cognition approximates Bayesian inference by sampling. A prediction and consequence of approximate inference by sampling is independent, identically distributed noise across multiple responses from one individual. Here I will review several experiments yielding support for this claim. I show that in visual attention tasks

(selection in space and time) multiple guesses about the identity of the target are independent and identically distributed. Further, in world-trivia tasks, when subjects are asked to make two guesses about questions like "What proportion of the world's airports are in the US?", their guesses are also independent. As a consequence of this independence, averaging two guesses from one individual yields a wisdom of a "crowd within": averaging multiple guesses from one individual yields a more accurate answer than either of the guesses alone.

Sunday, 16:20 (Session A)

Representing consensus and divergence in communities of Bayesian decision-makers. Kshanti Greene, *University of New Mexico* . We address the concept of wisdom of the crowds for subjective problems such as policy-making in which the population will typically have very diverging opinions and there is no single "correct" answer. We introduce a new approach to aggregating the beliefs and preferences of groups of individuals and demonstrate how to apply game theoretic analysis to large populations of Bayesian decision-makers. Belief aggregation approaches that form a single consensus model average away conflicting beliefs in a population and may even result in irrational solutions according to a set of properties for rational aggregation. In contrast, our approach maintains the diversity of a population and allows the competitive aspects of group decision-making to emerge. We form collective belief models in which collectives are formed from individuals who agree on the preference order over a set of decision alternatives. Using "super-agents" that represent each collective we demonstrate how game theoretic analysis and negotiation techniques can be used to enable and analyze rational social decision-making.

Sunday, 16:40 (Session A)

A Bayesian approach to aggregate knowledge: Comparing groups of independent and communicating individuals. Mark Steyvers, Brent Miller, *UCI*, Rob Goldstone, *Indiana University* . We analyze the collective performance of individuals in a series of general knowledge tasks involving the judgment of percentages and rankings of events and items. We compare situations in which individuals independently answer these questions with two group-decision making situations: an iterated learning environment in which individuals pass their solution to the next person in a chain and a Delphi-like method in which individuals can revise their answers after observing the solutions from other members of the group. We extract the shared knowledge in all these situations using a hierarchical Bayesian approach inspired by Cultural Consensus Theory. Consistent with previous research, the results indicate that group decision-making situations lead to correlated judgments. However, we show that a proper analysis of the data that takes the dependencies between individuals into account leads to strong wisdom of crowd effects where the aggregate performs as well as or better than the best individual in the group.

ACCEPTED TALKS

Sunday, 10:50 (Session C)

Subjective Loudness As A Ratio Scale Function of Both Intensity And Frequency. R. Duncan Luce, Ragnar Steingrimsson, Louis Narens, *UCI* . Using the methods of magnitude estimation and production, S. S. Stevens (1975) claimed without proof that when all other physical properties other than intensity are held fixed, then subjective intensity is a ratio scale of physical intensity. Narens (1996) proved that for this to be true a certain commutativity property must hold, and several empirical studies confirmed commutativity for loudness and for brightness. We address a more general question: Is the loudness function over all intensities and frequencies a single ratio scale that, for each frequency separately, is the usual loudness scale? Using Luce's (2004) axiomatic representation, which is more general than Narens', the answer is yes provided that a more general commutativity property holds. Data in support of generalized commutativity are reported. A question to be addressed in the future is: If another modality is also represented by a ratio scale, is

there a common subjective intensity over the two modalities?

Tuesday, 16:20 (Session C)

Emergence of Cooperation between Intelligent Individuals with Personality. Min-Hyung Cho, Soo-Young Lee, *KAIST* . In this paper, we have shown that cooperative behavior can be spontaneously evolved among intelligent individuals by adopting personality. Evolutionary prisoner's dilemma game in a grey-scale version, which we use as a model of real society, abstracts the essence of interaction between living beings. Our model of intelligence for players is composed of prediction network and action network. The prediction network models the environment based on the information from the outside. The action network simulates N-look ahead future and choose the next action that is expected to induce the best future outcome. The first proposed model can exploit or cooperate with fixed strategy players without difficulty, thus guaranteeing a moderate intellectual power. But it was hard to induce cooperation between proposed models because they could not get the accurate model of others and easily fell into mutual defection with no investment. By adopting personality to the first model the second model has solved this problem. We have tried two different characterizations of personality, namely CO and RS, and evolution experiments have yielded different dominant intelligent strategies. For CO characterization case, which compromises selfishness and altruism, the usual mutual defection strategy has become dominant out of initial random population. Whereas, for RS characterization which represents the level of greediness, mutual cooperation strategy has become dominant as a result of evolution. Two final strategies can also be shown to be evolutionarily stable.

Sunday, 16:20 (Session B)

A computational model of the recovery of a 3D scene from a single 2D camera image. Yunfeng Li, Joseph Catrambone, Stephen Sebastian, Tadamasa Sawada, Zygmunt Pizlo, *Purdue University* . Our recovery model is applied to images of real scenes containing multiple pieces of furniture. The model consists of several steps. First, individual objects are found in the 2D image and separated from each other and from the background. The image is obtained by a calibrated camera (the focal distance and the principal point are known). This is accomplished by a combination of region growing and contour detection. The occluding contour of a single object is represented by an alpha-hull of a region encompassing homogeneous texture. Alpha-hull is a generalization of a convex hull. Next, contours inside each alpha-hull are detected and grouped. These internal contours are essential for producing a 3D interpretation of each object. The 3D shape of the object is recovered by applying several a priori constraints (3D symmetry, orthogonality, 2D and 3D compactness, planarity of the contours). An inclinometer mounted on the camera provides information about the direction of gravity. This information is similar to the information provided by the human vestibular system. Information about gravity is used to determine the horizon and the vanishing point representing edges that are vertical in the 3D scene. The 3D scene is recovered by placing the individual 3D shapes on the common floor, whose distance from the camera is known. The recovered scene is usually very close to the real one and it is complete in the sense that it has information about the back, invisible parts of the objects as well as the front, visible ones.

Sunday, 16:40 (Session B)

Any 2D image is consistent with a 3D symmetrical interpretation. Tadamasa Sawada, Yunfeng Li, Zygmunt Pizlo, *Purdue University* . Our everyday life experience suggests that we can easily tell the difference between 3D symmetrical and asymmetrical shapes. Computationally, discriminating between 3D symmetrical and asymmetrical shapes from a single 2D retinal image is a difficult problem because the 2D retinal image of a 3D shape is almost always asymmetrical regardless whether the 3D shape is or is not symmetrical. One possible method to perform this discrimination is to verify whether a given 2D retinal image is geometrically con-

sistent with a 3D symmetrical interpretation. Unfortunately, this method will not work because 3D symmetrical interpretations are almost always possible. We prove, under very general assumptions, that any pair of curves in a single 2D image is consistent with a pair of 3D symmetrical curves. It is also trivially true that any pair of curves in a single 2D image is consistent with a pair of 3D asymmetrical curves. It follows, that discrimination between 3D symmetrical and asymmetrical interpretations is geometrically impossible. So, how can a human observer discriminate between symmetrical and asymmetrical 3D shapes? We discuss the role of higher-order features (like corners) in determining the point correspondences, as well as the role of a planarity constraint in this task. When the correspondence of features is known and/or curves can be assumed to be planar, 3D symmetry becomes non-accidental. In other words, a 2D image of a 3D asymmetrical shape obtained from a random viewing direction is unlikely to be consistent with 3D symmetrical interpretations.

Monday, 16:40 (Session A)

Cognitive Models, the Wisdom of Crowds, and Sports Predictions. Michael Lee, *UCI* . The Wisdom of Crowds framework has been applied not just to general knowledge problems, where there is an existing ground truth, but also to prediction problems, where the ground truth is only established later. This talk presents some case studies in predicting sporting outcomes, exploring the role that cognitive models can play to improve the aggregation of expert and non-expert human opinions. One case study involves predicting NBA ladders, based on a mixture of expert and non-expert predictions. Another involves predicting NFL game winners, based on regularly revised expert assessment. A third involves predicting the "March Madness" College Basketball tournament, where there is strong prior information. Collectively, these examples highlight the potential and challenges in using hierarchical generative cognitive models to make aggregated predictions.

Tuesday, 15:20 (Session A)

An Integrated System Analysis of Gain and Orienting Models of Attentional Selection. Philip Smith, David Sewell, *The University of Melbourne* . The classical attention literature offers two alternative conceptions of the brain's limited capacity processing resources and how resources are allocated: orienting models and gain models. Orienting models have their origins in Broadbent's filter theory and Posner's spotlight of attention. They hold that, in order to identify a stimulus, a limited-capacity, possibly serial, stimulus identification mechanism must be switched to, or aligned, with the stimulus location. Gain models have their origins in Kahneman's capacity theory. They hold that capacity can be distributed variably across stimulus locations in accordance with attentional set, and that the processing efficiency at any location is proportional to the capacity allocated there. Smith and Ratcliff (*Psychological Review*, 2009) compared gain and orienting models in their integrated system theory of visual attention and found that their predictions in a Posner spatial cuing task were indistinguishable. We report two new experiments based on Yantis and Jonides' no-onset paradigm, in which stimuli are created by removing features from existing perceptual objects. RTs to unattended stimuli were longer and accuracy was lower in a no-onset condition than in a condition with onset transients. Fits of the integrated system model show the data were better described by a model in which processing resources are reallocated in response to onset transients than one in which resources are allocated only once, at the beginning of a trial. We characterize the results using Sperling and Weichselgartner's episodic theory, which views gain and orienting as the spatial and temporal dimensions of an attentional control function.

Tuesday, 15:20 (Session C)

A non-probabilistic measure of relational information based on Categorical Invariance Theory. Ronaldo Vigo, *Ohio University* . In what follows, we introduce a measure of relational information that is not based on probability theory. The measure is based on a unification of invariance, complexity and information

notions in concept learning research. The idea is to use categorical invariance theory (Vigo, 2008, 2009) to characterize the subjective relational information that a Boolean set R carries about its superset S as the rate of change in the subjective structural complexity of S (as defined by the degree of categorical invariance of S) whenever the objects in R are removed from the set S. We ran an experiment which shows that humans find an object more informative in respect to its category of origin when there is a relatively large decrease or large gain in the subjective structural complexity of the category without the object; likewise, less informative when there is a relatively small decrease or small gain in the subjective structural complexity of the category without the object. Our subjective relational information model successfully fits this data. This talk also serves as an introduction to categorical invariance theory which posits that the degree of subjective learning difficulty of a Boolean category (and of its corresponding concept) is a function of its degree of categorical invariance.

Sunday, 10:50 (Session B)

Towards a unified account of decisions from experience and description. Scott Brown, Guy Hawkins, Pennie Dodds, Ben Newell, Adrian Camilleri, *University of Newcastle, Australia* . Research on risky decision making has focused on problems in which the choice alternatives are described to observers ("Would you prefer a sure gain of \$3 or an 80% chance of a \$4 gain with a 20% chance of no gain?"). Some more recent research has found that different decisions are often made observers learn these task parameters by repeatedly sampling outcomes from the alternatives. We present a theoretical framework that is aimed towards accounting for choice preferences in both experience and description paradigms. We also evaluate the model using a new stream of data provided by the experience paradigm: observers not only provide choices between alternative gambles, but also judgments about the outcomes and probabilities associated with each gamble.

Tuesday, 9:20 (Session B)

ROC analyses of confidence responses and reaction times in recognition memory. Christoph Weidemann, *Swansea University*, Michael Kahana, *University of Pennsylvania* . A central assumption in models of recognition memory is that memory strength is variable. In an effort to assess memory strength on a trial-by-trial basis, many recognition studies ask participants to qualify the binary recognition response with confidence ratings. We investigated the question to what extent information contained in such confidence ratings might already be present in reaction times of binary "old"/"new" decisions. Novel ROC-based measures quantify to what extent either dependent variable contains information about intermediate states within each recognition response. We show that in many cases there is a close correspondence between information gained from confidence ratings and from reaction times to binary recognition decisions.

Monday, 10:50 (Session B)

Computer-Based Assessment of Working Memory Using Computer Games. Misha Pavel, Holly Jimison, *OHSU* . As a part of a large longitudinal study focused on early detection of cognitive decline in the aging population, we have been investigating ways to monitor cognitive processes using unobtrusive techniques combined with real-life cognitive tasks. We developed a number of computer games which, much like in everyday cognitive tasks, require concurrent execution of multiple cognitive processes. Mathematical models are required to estimate the key characteristics of the underlying cognitive processes. In this presentation we illustrate this approach using a computer game of concentration. At the start, a player is confronted with a matrix of images of playing cards displayed face-down and asked to turn two cards on each trial. The players goal on each trial is to identify (i.e., to turn) two matching cards using the player's memory of previously exposed card face value and location. The key cognitive process required to play this game is working memory. A player's working memory is represented by a leaky buffer of previously seen

cards; each item can be lost stochastically from the buffer. The duration of an item in working memory is described in terms of survival analysis characterized by a hazard function derived from a Weibull distribution. After removing the effects of guessing (i.e., a model of a random player), the parameters of the maximum likelihood fit of the distribution are used to characterize the working memory of each player. We will demonstrate the applicability of the model and its use to track individual players' working memory over time.

Tuesday, 12:10 (Session B)
Multinomial Processing Tree Models and Bayesian Networks: Some formal results. Brendan Purdy, *Moorpark College*, William Batchelder, *University of California, Irvine* . Multinomial Processing Tree (MPT) Models are class of statistical models applied to cognitive phenomena. They have been widely used within the field of mathematical psychology. It is important to note that the tree structure of MPT models is intended to represent cognitive processes. The first set of propositions of this paper concerns the enumeration and statistical equivalence of various subclasses of MPT models. That is, the paper states a number of results regarding how many models there are for certain types of MPT models and when these models can be said to be statistically equivalent to one another. The proofs of these propositions are built on the formalization of Binary MPT models in Purdy and Batchelder (2009, *JMP*). These formal results lead to a theorem in the paper about the relationship between MPT models and Bayesian networks. Bayesian networks (Bayes nets) are a class of statistical models that are widely used in both computer science and cognitive science. In particular, the theorem demonstrates that MPT models are a subclass of Bayes nets. The proof of this theorem depends on expanding the numbers of random variables that are built into the class of MPT models. An important aspect of this paper is the discussion of why these theorems are relevant to the researcher in the field or the lab.

Sunday, 11:50 (Session C)
A new probability theory for belief and decision. Louis Narens, *UCI* . Normative and descriptive theories of belief and decision are almost always formulated in terms of a finitely or countably additive probability function on a boolean algebra of sets. This talk investigates looking at a weaker algebra of subsets upon which to base finitely and countably probability theory for representing psychological and normative representations of belief and decision. Philosophical and modeling justifications for the new probability theory are presented and applications to are discussed.

Sunday, 9:20 (Session C)
Quantitative Testing of Decision Theories: II. Empirical Testing. Chris Zwilling, Michel Regenwetter, William Messner, Anna Popova, *University of Illinois* . We carry out a series of quantitative tests of leading theories of decision making, including Expected Utility theory, Cumulative Prospect theory and the Transfer-of-Attention-Exchange model. All of these tests avoid aggregation paradoxes by analyzing data within respondent only. The tests are based on novel "distance-based," "aggregation-based," and "mixture-based" probabilistic specifications, all of which require state-of-the-art order-constrained inference. All of these tests turn out to be extraordinarily powerful. We reinforce other authors' warning that probabilistic specification of algebraic theories cannot be taken lightly.

Monday, 16:00 (Session B)
Application of a Robust Differencing Variable (RDV) Technique to the Department of Veterans Affairs Learners' Perceptions Survey. Richard Golden, *University of Texas at Dallas*, Steven Henley, *Martingale Research Corporation*, Halbert White, *University of California at San Diego*, Michael Kashner, *UT Southwestern Medical Center at Dallas* . An important problem in policy analysis is measuring the effect of a factor using observational data by comparing response outcomes from a a "factor-present" condition with responses to a non-randomized control condition where the factor is absent. We thus introduce the Robust Differencing Variable (RDV) Tech-

nique that applies Robust Missing Data Theory (Golden, Henley, White, and Kashner, submitted). To isolate group factor effect size, a "differencing variable" is introduced to indicate whether the factor, when present, will produce an effect or produce no effect, on the response variable. By their nature, differencing variables are observable in the factor-present condition, but are usually unobservable in control conditions. Treating the partially or completely unobservable differencing variable in the control condition as Missing at Random (MAR) we show how to measure a group factor effect-size. This is accomplished by computing the association between the response outcome and an interaction between the differencing and group factor indicator variables so that the resulting maximum likelihood estimates, standard errors, and hypothesis tests are robust to model misspecification. We apply this strategy to the Department of Veterans Affairs (VA) Learners' Perceptions Survey of medical physician residents to assess the impact of an 80-hour work week limit on medical education. Our results provided evidence that the 2003 clinical duty limits had positive impacts on clinical learning environments, a finding that offers profound policy implications on how physicians will be trained in the U.S. in the future.

Tuesday, 11:50 (Session B)

A String Language for Multinomial Processing Tree Models. William Batchelder, *UC Irvine*, Brendan Purdy, *Moorpark College*, Xiangen Hu, *U Memphis* . Traditionally Binary Multinomial Processing Tree (BMPT) models are defined as rooted full binary trees, where manifest categories are associated with the leaves (terminal nodes) and parameters with the non-terminal nodes of the tree. Purdy and Batchelder (2009, *JMP*) provide five recursive axioms that provide a new definition of the class of BMPT models. Those axioms represent BMPT models as formal strings of parameter and category symbols along with computational rules that apply to the strings to generate category probabilities. The string language is shown to derive from a formal context free grammar, and further the class of strings so defined coupled with the computational rules is shown to be formally equivalent to the class of BMPT models defined in the traditional way. This paper will extend the string language in three directions. First we will generalize the string language to handle multi-link MPT (MMPT) models where non- terminal nodes can have more than two children. Second we will exhibit transformational rules on multi-link MPT model strings that generate statistically equivalent BMPT model strings. Finally we will reconsider the problem of parametric order constrains in BMPT models discussed in Knapp and Batchelder (2004, *JMP*) by developing string transformational rules that will generate statistically equivalent, unconstrained BMPT models from strings representing BMPT models subject to parametric order constrains. Viewed generally the string language provides a very succinct representation of BMPT models that can aid in theorem proving and facilitate input to computational statistical algorithms.

Monday, 15:20 (Session C)

Evolutionary models of color categorization based on realistic observer models and population heterogeneity. Kimberly A. Jameson, Natalia Komarova, *UCI* . The evolution of population color categorization systems is investigated using game theory simulation techniques. Categorization systems are based on human empirical data in the form of Farnsworth-Munsell 100 Hue Test results to, in part, model artificial agents with some realistic constraints from human populations. Constraints include (i) varying amounts of normal observer heterogeneity, and (ii) varying degrees and forms of observer color deficiency, and are made operational in agent categorization and communication games. They produce a number of interesting consequences for stable, shared categorization solutions that are evolved in agent populations. It is found that the confusion patterns associated with a small fraction of color deficient agents break symmetries in population categorization solutions, and confine the boundaries of color

categories to a small subset of available locations. Further, confusion pattern variations across different types of deficient agents lead to changes in category size and number that depend on the form of deficiency represented. In particular, stimulus pairs forming global confusion axes for dichromats tend to attract color boundaries, and local confusion regions characteristic of both dichromats and anomalous trichromats tend to repel color boundaries. Furthermore, the concurrent presence of normal agents and several different kinds of deficient agents produces novel constrained solutions that optimize successful categorization performance in population communication games involving color.

Tuesday, 12:10 (Session C)

Remarks on quantum cognition. Geoff Iverson, *UCI* . In October 2009 a special issue, Volume 53 (5), of the *Journal of Mathematical Psychology* was devoted to the emerging field of quantum cognition. In their introductory article the editors of this special issue noted that "Several phenomena in psychology that have stubbornly resisted traditional modeling techniques are showing promise with a new modeling approach inspired by the formalism of quantum mechanics." In examining this provocative claim I pay close attention to the way in which quantum formalism is implemented in the construction of cognitive models, and to the data that these models seek to explain.

Sunday, 9:00 (Session C)

Quantitative Testing of Decision Theories: I. Probabilistic Specification. Michel Regenwetter, *University of Illinois*, Clintin Davis-Stober, *University of Missouri*, Shiau Hong Lim, *Universitaet Leoben*, William Messner, *University of Illinois* . We provide a new quantitative framework for testing algebraic theories of pairwise preference on binary choice data. This framework bridges the conceptual, mathematical, and statistical gap between algebraic decision theory in the deterministic realm and highly variable empirical data that originate from sampling processes in the laboratory. We discuss several probabilistic specifications that all leverage breakthrough developments in statistical inference. We also illustrate the formal implementation of these specifications for leading current theories of decision making.

Sunday, 15:40 (Session B)

Human four-dimensional spatial judgments on hyper-volume. Ranxiao Frances Wang, *Univ. of Illinois at Urbana-Champaign* . Living in a 3D physical world, humans have their perceptual and cognitive systems tailored for 3D objects. However, a recent study by Ambinder et al (2009) demonstrated humans ability to learn and make basic spatial judgments (distance and angles) on 4D geometric objects viewed in virtual reality with minimal exposure to the task and no feedback to their responses. The current case study further examines human judgments of hyper-volume, a novel property unique to higher dimensional space. One experienced observer was tested in 20 trials. In each trial, the participant studied a 3D parallel projection of a random wireframe hyper-tetrahedron (4-simplexes) rotating along the wx-plane for 2 minutes. Then the hyper-tetrahedron disappeared and a cube appeared representing the base of a hypercube. The participant adjusted the size of the cube until the hyper-volume of the hypercube it represented and the hyper-tetrahedron matched. To account for the 3D strategy which uses averaged 3D volume to approximate the hyper-volume, a multiple regression was run on the responses as a function of both the actual hyper-volume and the mean 3D volume to measure people's true hyper-volume judgments. The correlation between the hyper-volume and the mean 3D volume was moderate ($r = .37$), suggesting the two factors can be separated. More importantly, the multiple regression showed a significant effect of hyper-volume ($\beta = .71$, $t = 3.71$, $p < .01$) but not mean 3D volume ($\beta = .04$, $t = .22$, $p = .82$). These findings suggest that at least some people are able to judge 4-D hyper-volume, which indicates the true 4D spatial representations.

Tuesday, 9:00 (Session B)

On Incorporating Item Effects into Signal Detection Theory. Lawrence DeCarlo, *Columbia University* . Applications of signal detection theory (SDT) often involve the presentation of different items on each trial, such as different words in a memory study or different slides in a medical imaging study. It has long been recognized that factors particular to the items themselves might affect observers responses. Here it is noted that there are different ways to incorporate item effects into SDT, depending on how the situation is conceptualized. For example, a latent continuous variable that represents item effects can be assumed to affect only one event, such as the signal, or can be assumed to affect both events, that is, signal and noise. An example is a medical training study where trainees attempted to detect fractures in X-ray slides of ankles (where the true state of the ankle was known). The SDT model gives estimates of a trainees ability to discriminate fractures from non-fractures and his or her use of response criteria. The idea underlying the extended SDT model is that the slides also differ in terms of difficulty, which can be captured by a latent difficulty variable that affects the discrimination parameter. A model where only fractures differ in detection difficulty is compared to a model where both fractures and nonfractures differ in difficulty. The extended model is a type of random coefficient model and can easily be fit with maximum likelihood estimation using standard software. The extension incorporates an item-response theory (IRT) model into an SDT model, with simultaneous estimation of both components.

Tuesday, 11:30 (Session C)

Cortico-Striatal Connections Predict Control over Speed and Accuracy in Perceptual Decision Making. Birte Forstmann, *University of Amsterdam*, Alfred Anwander, Andreas Schäfer, Jane Neumann, *Max Planck Institute*, Scott Brown, *University of Newcastle*, Eric-Jan Wagenmakers, *University of Amsterdam*, Rafal Bogacz, *University of Bristol*, Robert Turner, *Max Planck Institute* . When people make decisions they often face opposing demands for response speed and response accuracy, a process likely mediated by response thresholds. According to the striatal hypothesis, people decrease response thresholds by increasing activation from cortex to striatum, releasing the brain from inhibition. According to the STN hypothesis, people decrease response thresholds by decreasing activation from cortex to subthalamic nucleus (STN); a decrease in STN activity is likewise thought to release the brain from inhibition and result in responses that are fast but error-prone. To test these hypotheses—both of which may be true—we conducted two experiments on perceptual decision making in which we used cues to vary the demands for speed vs. accuracy. In both experiments, behavioral data and mathematical model analyses confirmed that instruction from the cue selectively affected the setting of response thresholds. In the first experiment, we used ultra high-resolution 7T structural magnetic resonance imaging (MRI) to locate the STN precisely. We then used 3T structural MRI and probabilistic tractography to quantify the connectivity between the relevant brain areas. The results showed that participants who flexibly change response thresholds (as quantified by the mathematical model) have strong structural connections between presupplementary motor area and striatum. This result was confirmed in an independent second experiment. In general, these findings show that individual differences in elementary cognitive tasks are partly driven by structural differences in brain connectivity. Specifically, these findings support a cortico-striatal control account of how the brain implements adaptive switches between cautious and risky behavior.

Monday, 10:00 (Session B)

Looking to Learn, Learning to Look: Attention Emerges from Cost Sensitive Information Sampling. Bradley Love, *University of Texas at Austin* . Given people's capacity limitations, one key aspect of learning is learning which stimulus aspects are goal relevant in the current context. In addition to injecting noise into the decision process, gathering unnec-

essary information can have costs in terms of time, effort, dollars, fuel, etc. Accordingly, many category learning models employ selective attention mechanisms that learn which stimulus dimensions are most critical to performance. However, attention in category learning models does not direct what is encoded, but instead establishes decision weights on stimulus dimensions. According to existing models, all stimulus dimensions are encoded, which is not realistic, nor supported by basic research in attention. To address these shortcomings, I develop a model that selectively encodes information during learning as a function of the learner's goals, task demands, and knowledge state. The model consists of two components that are both normative, but lead to apparent non-normative behaviors when linked. One component determines the value of potential sources of information. The value of a piece of information depends on the decision maker's goals and assumptions about (i.e., knowledge of) the world, as well as the cost of the information. The second component of the model reflects the decision maker's knowledge of the world, which is used by the first component to direct information gathering. This learning component of the model is updated by the information samples selected by the first component, completing the cycle of mutual influence. The model accounts for accuracy and eye movement data during category learning tasks.

Sunday, 12:10 (Session A)

Diffusion versus Linear Ballistic Accumulation: Different Models for Response Time, Same Conclusions about Psychological Mechanisms? Chris Donkin, *Indiana University*, Scott Brown, Andrew Heathcote, *The University of Newcastle*, Eric-Jan Wagenmakers, *University of Amsterdam*, Richard Shiffrin, *Indiana University* . Quantitative models for response time and accuracy are increasingly used as tools to draw conclusions about psychological processes. Here we investigate the extent to which these substantive conclusions depend on whether researchers use the Ratcliff diffusion model or the Linear Ballistic Accumulator model. Simulations show that the models agree on the effects of changes in the rate of information accumulation and changes in non-decision time, but that they disagree on the effects of changes in response caution. Fits to empirical data show, however, that the models agree closely on the effects of experimental manipulations, both within and across groups, even when that manipulation affects response caution. We conclude that—in real data—researchers can analyze their data with either model, as the conclusions about psychological processes are unlikely to depend on the model that is used. As further confirmation of the interchangeability of the two models we also find that they have equivalent complexity.

Tuesday, 15:40 (Session A)

Guided Visual Search. Chris Donkin, *Indiana University*, Denis Cousineau, *University of Montreal*, Richard Shiffrin, *Indiana University* . Cousineau and Shiffrin (2004) presented a model for the control conditions of a visual search study. Multiple modes were observed for target present trials and the model posited serial terminating comparisons, partially and probabilistically guided to the target location by a separate parallel automatic process. We expand and extend this model to the experimental conditions in which the visual display objects are presented successively, at speeds fast enough that the displays appear simultaneous. These successive display conditions place strong constraints on models, and allow us to develop a quite precise account for parallel and serial processes operating together in visual search.

Monday, 16:00 (Session C)

Color charts, aesthetics, and subjective randomness. Yasmine Sanderson, *Friedrich-Alexander University Erlangen* . Much of the previous research in subjective randomness has considered it within the framework of binary sequences and grids (see Bar-Hillel and Wagenaar (1991) or Nickerson (2002) for a survey). In this study, we consider subjective randomness within the additional framework of color. A statistical analysis of fifty-four "random-looking" art and design color charts show that they differ significantly from normal in the average jump be-

tween adjacent colors. The charts in question are human-generated and show no obvious patterns or symmetries and are not likenesses of some person, place or object. An example of one such chart is:

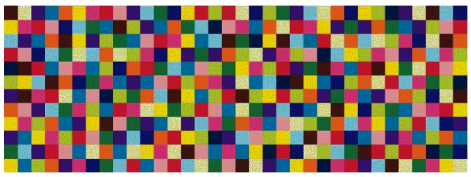

Figure 1: *Happy Pixels* by Sieger Design

We argue that this (and many of the other) color charts are examples of subjective randomness. Our results suggest that color distance is a factor in subjective complexity. We also argue that the large percentage of design color charts with superalternation indicate an aesthetic value to this trait.

Sunday, 9:00 (Session B)

Adaptive Design Optimization for Testing Generalized Utility Theories. Daniel Cavagnaro, Jay Myung, Mark Pitt, *Ohio State University*, Richard Gonzalez, *University of Michigan* . We present a Bayesian framework for comparing generalized utility theories. In this framework, each theory is cast as a parametric Bayesian model based on a qualitative pattern of indifference curves (e.g., parallel straight lines, straight lines fanning out, or convex curves). Bayesian model selection tools can then be used to weigh the evidence for each theory. Data that can effectively discriminate between theories are obtained from binary choice experiments using Adaptive Design Optimization (ADO), in which the gamble pairs are not randomly drawn but rather carefully selected to maximally discriminate the theories under consideration. Data from a simulation study will be presented in which the fanning out hypothesis is tested by comparing Expected Utility and Weighted Expected Utility.

Tuesday, 10:00 (Session C)

Does Hierarchical Complexity of Items Predict Synchrony Across Content and Gaps Between Stages? Michael Commons, *Harvard Medical School*, Andrew Richardson, *Dare Institute* . This study analyzed items from five variations of a problem that required the isolation of variables. The purpose of this analysis was to determine the relationship between order of hierarchical complexity of items, their content, and language and participant performance on the items. Participants were English, German and Arabic speaking. The five variations of the isolation of variables problem that were given were: 1) Arabic Laundry; 2) United States Laundry; 3) Short Laundry; 4) Combustion; 5) Atheism and Belief. A Rasch analysis produced stage scores for each of the items from each of the instruments. These item Rasch scores were regressed against the order of hierarchical complexity of each of the items, $r = .95$ (Arabic Laundry); $r = .963$ (United States Laundry); $r = .940$ (Short Laundry); $r = .797$ (Combustion); $r = .787$ (Atheism and Belief). The analysis showed that Hierarchical Complexity was the greatest predictor of variance $r = .898$, $p < .01$ when compared against both content and language, together and individually. We showed that the ordinal nature of the order of hierarchical complexity was reflected in gaps between stage scores.

Tuesday, 9:20 (Session C)

Can Perceived Value Be Explained by Schedules of Reinforcement?. Nicholas Commons-Miller, *Tufts University*, Michael Lamport Commons, *Harvard Medical School*, Robin Gane-McCalla, *Dare Institute* . Can schedules' perceived value be explained by the perceived value of just a few reinforcers? The additive noise model states that discounted reinforcer value simply adds together linearly but as time passes noise is added, V_O = Overall value = $\sum v_i$ where v_i = effective or perceived value of a reinforcer at time i Our unified theory integrates initial value of outcomes, delay and risk. Results from samples suffice to characterize entire schedules. Three derivatives of immediate reinforcer value with respect to time of a reinforcer summate many properties of discounting accounts of reinforcement schedules. A trial consisted of a two chain schedule. The

first link consisted of the presentation of one of a large number of samples from a t schedule (Schoenfeld & Cole, 1972). The second link was a choice between a left key indicting the sample was lean or the right key indicating it rich. The value of an instantaneous reinforcer is A_i. The perceived sample value was an hyperbolic function of how soon before choice a single reinforcer was (first derivative) as the Commons et al. (1982)/Mazur's (1987) equation for delay, $v_i(\text{delay}) = A_i/(1 + k_1 d_i)$. Risk is the derivative of Commons et al. (1982)/Mazur's (1987) equation for delay: $v_i(\text{risk}) = -A_i k_2/(k_2 d_i + 1)^2$ was well fit by a negative power function as proposed.

Sunday, 11:10 (Session C)

A Criterion and Tests for Selective Probabilistic Causality. Ehtibar Dzhafarov, *Purdue U*, Janne Kujala, *JyvS̈ession AskylS̈ession A U* . A general definition and a criterion (a necessary and sufficient condition) are formulated for an arbitrary set of external factors to selectively influence a corresponding set of random variables, jointly distributed at every treatment (i.e., a set of factor values containing precisely one value of each factor). The variables are selectively influenced by the corresponding factors if and only if there is a jointly distributed set of random variables, one variable for every value of every factor, such that every subset of this set that corresponds to a treatment is distributed as the original variables at this treatment. We call this the joint distribution criterion for selective influence. It is applicable to any set of random entities (not necessarily numeric) and any set of factors. The *distance tests* (necessary conditions) for selective influence previously formulated for two random variables in a two-by-two factorial design are extended to arbitrary sets of factors and random variables. A distance test consists in choosing a number $p \geq 1$, two distinct factors, μ and ν, and two distinct values (x^μ, u^μ) and (y^ν, v^ν) for each of them, and ascertaining whether

$$\max\{Dx^\mu y^\nu, Dx^\mu v^\nu, Du^\mu y^\nu, Du^\mu v^\nu\} \leq \frac{1}{2}\left(Dx^\mu y^\nu + Dx^\mu v^\nu + Du^\mu y\nu + Du^\mu v^\nu\right),$$

where D for two factor values is defined as $(E(|A - B|^p))^{1/p}$, with A and B being the random variables (or some measurable transformations thereof) corresponding to these factor values. If the inequality is violated for at least one choice of (x^μ, u^ν), (y^μ, v^ν), p, and of the measurable transformations, selective influence is ruled out.

Monday, 9:00 (Session C)

Fundamental Properties of Reverse Hazard Functions. Richard Chechile, *Tufts University* . The hazard function $h(x)$ for a continuous random variable x is defined as $f(x)/[1 - F(x)]$. There are many applications of hazard function analysis in psychological research, thereby attesting to the utility of this probabilistic construction. Yet in stochastic modeling there also is a reverse hazard function $r(x)$, which is defined as $f(x)/F(x)$. Although less is known about reverse hazard functions and fewer applications can be found for these functions in comparison to hazard functions, there are many interesting and useful properties of reverse hazard functions that have the potential for application in psychological research. In this paper, some new results concerning reverse hazard functions are developed.

Tuesday, 16:00 (Session C)

Changing Minds: Estimation of Multiple Preference States Via Normalized Maximum Likelihood. Clintin Davis-Stober, *University of Missouri* . Given multiple presentations of two choice alternatives, decision makers do not deterministically choose one alternative over another. I present a "branch and bound" algorithm that: 1) classifies whether an individual decision maker is making choices according to a single or multiple preference state(s) consistent with a pre-specified theory, and 2) estimates an optimal mixture distribution over those preference states using normalized maximum likelihood. I re-examine several existing datasets collected to test a variety of measurement axioms and paradoxes using this methodology.

Sunday, 12:10 (Session B)

The effect of losses on maximization:

Loss aversion versus a global-effect model. Eldad Yechiam, *Technion - Israel Institute of Technology* . Previous findings have shown that losses increase performance level in abstract tasks compared to rewards. Additionally, it has been shown that losses increase maximization: The so called "successful loser" effect (Bereby-Meyer & Erev, 1998). The current paper examines three simple quantitative models that account for the effect of losses on maximization. The first model involves loss aversion whereby there is an asymmetry in the weight of losses compared to gains (following prospect theory). The second and third models are global-effect models assuming that losses increase the subjective weight of all outcomes associated with the loss-producing alternative, including gain components. An additive global-effect model (whereby payoff is increased by a positive parameter c) is compared to a multiplicative global-effect model (whereby payoff is multiplied by a parameter c with a value greater than 1). The predictions of the three models regarding the necessary conditions for the successful-loser effect are examined in three published datasets (Ert & Yechiam, 2007; Haruvy & Erev, 2002, and Levin, Weller, Pederson, & Harshman, 2007). The results show that the only model consistent with the pattern observed in all three studies is the multiplicative global-effect model. The adaptive advantage of the global-effect model is that it does not assume that absolute losses impair exploration or maximization (compared to relative losses) when they are presented along with equal or larger gains.

Monday, 9:20 (Session B)

Exploring Active Learning in a Bayesian Framework. Stephen Denton, John Kruschke, *Indiana University* . Bayesian approaches to learning involve incrementally updating degrees of belief across a space of hypotheses whenever an observer passively observes a stimulus and outcome. But these approaches also provide a framework for models of active learning – learning in which stimuli are actively probed to disambiguate potential beliefs regarding outcomes. Within a Bayesian framework, uncertainty across beliefs is inherently represented and thus the expected uncertainty reductions for candidate stimuli can be evaluated. Bayesian active learning models offer the prediction that an active learner would select the stimuli for which the expected uncertainty across all hypotheses is minimized. This research contrasts four possible hypothesis spaces for active learning consisting of two simple cue-combination models and two possible priors. To tease apart the models, an automated search of associative learning structures for which the models make maximally different predictions was performed. Human participants were tested on these same learning structures in the context of an allergy diagnosis task. At various points in training, participants were asked which cues they would find the most informative to learn about; i.e., their active learning preferences were assessed. The model and prior combinations that best mimic human active learning will be discussed.

Monday, 11:10 (Session B)

Computer-Based Assessment of Planning and Problem Solving. Holly Jimison, Stuart Hagler, Misha Pavel, *Oregon Health & Science University* . Planning abilities are a key component of cognitive health and important to problem solving. These abilities are often compromised with brain injury, stroke, and neurological disease. Computerized, model based assessment of these abilities can be used in care and rehabilitation. To address this issue, we developed a research version of the popular computer game FreeCell that enabled us to manipulate the planning difficulty. This computer card game is a version of Solitaire where the initial state is a random arrangement of cards in 8 work piles. The player must move these cards 'constrained by the order and by suit' and employing 4 free piles in such a way that the resulting state is 4 home piles of sorted cards. We adapt the initial card layout to the skill level of each individual user and monitor the user's efficiency in moving toward solution by comparing our automated solver algorithm to human performance. The planning ability is then estimated to be the efficiency of the player relative to the ideal so-

lution compared to random guessing. By monitoring the naturalistic game play in the home over time in this way, we are able to characterize within-subject trends in planning or executive function, as well as variability in the cognitive measures over time. To summarize the results we developed a metric that appears to be correlated with traditional tests of cognitive abilities. We have demonstrated our ability to keep users engaged with this game and have integrated it into a cognitive health coaching intervention.

Monday, 15:40 (Session C)

Evolution and cognitive cost of ethnocentrism. Artem Kaznatcheev, *McGill University* . There is mounting evidence that ethnocentrism - commonly thought to rely on complex social cognition - may arise through biological evolution in populations with minimal cognitive abilities. We use the tools of evolutionary game theory and computational modeling to examine the evolution of ethnocentrism in a competitive world. We create a competitive environment through Prisoners dilemma interactions between agents in a spatial lattice where groups are marked by arbitrary tags uncorrelated to strategy or location. Ethnocentric agents are able to differentiate between in- and out-group partners, and adjust their behavior accordingly (cooperating with in-group and defecting from out-group). Humanitarian or selfish agents never make this distinction and always cooperate or defect, respectively. Thus, ethnocentric agents can be seen as more cognitively complex, and we associate a fitness cost with this complexity. We test the robustness of ethnocentrism, concluding that ethnocentrism is not robust against increases in cost of cognition. This suggests that the underlying mechanism behind ethnocentrism cannot be as complex as previously believed. Further, we address several hypotheses on the evolution of ethnocentrism in spatial models. We confirm that humanitarians are suppressed largely by ethnocentrics. Paradoxically, we observe that the proportion of cooperation is higher in worlds dominated by ethnocentrics. Suppressing free-riders, such as selfish and traitorous agents, allows ethnocentrics to maintain higher levels of cooperative interactions. We believe this research program can provide a new unifying strand between mathematical biology—evolutionary game theory and population dynamics—and cognitive science.

Tuesday, 9:40 (Session B)

Modeling Multitrial Free Recall. James Pooley, Michael Lee, *UCI*, William Shankle, *Medical Care Corporation* . We develop a simple psychological measurement model, based on the SIMPLE model (Brown, Neath, & Chater 2007), for multitrial free recall tasks in which individuals are presented with identical words with word order fixed across the tasks. Existing models for multitrial free recall have typically assumed randomized intertask word order, and we compare our model with these in terms of its ability to account for various serial position curves. We discuss the importance of fixed versus randomized intertask word order in multitrial free recall tasks, and discuss the potential use of our model in a clinical setting.

Monday, 16:20 (Session A)

A Bayesian Analysis of the Wisdom of Crowds Within. Brent Miller, Michael Lee, Mark Steyvers, *University of California, Irvine* . When averaging estimates from individuals, the aggregate often comes closer to the true answer than any individuals guess. Assuming an individuals guess is drawn from amongst a range of potential responses, would an aggregation of several of these responses also exhibit a "wisdom of crowds" effect? Vul and Pashler (2008) found evidence for this using tasks where individuals gave simple numerical estimates. In this study, we examine this wisdom of crowds effect for a series of ranking tasks, where the goal is to reconstruct, from memory, the order of time-based events or the magnitude of physical properties. Each task is performed twice, with an intervening distractor task. We combine the two estimates from each individual to form a wisdom of crowds aggregation. We then introduce a Bayesian measurement model to describe individuals performances across questions and across repetitions, and to measure differences between

the individual responses and the aggregated estimates. In results consistent with Vul and Pashler, we show that an individuals second estimate generally does not improve upon the first, but that the aggregate of the two is more accurate than either individual response.

Monday, 11:30 (Session B)

Toward a Cognitive Model of a Computer-Based Trail Making Test. Kyle Ambert, Holly Jimison, Misha Pavel, *Oregon Health & Science University* . The Trail Making Test (TMT) is a two-part neuropsychological assessment used as a measure of visual search and motor-control ability (TMT-A), as well as an index of cognitive set-switching capacity (TMT-B). Although ubiquitous in the clinical practice and neuropsychological research, few extensions to the TMT exist with the ability to track changes in player's performance over time. In this paper we describe a version of the TMT that was adapted as a computer game, allowing essentially an unlimited number of presentations and supporting variable degrees of difficulty. This computer game, called Scavenger Hunt, was included in a longitudinal study that allowed us to assess and monitor the performance of elder participants over more than one year. The data were analyzed using a simple additive model of the contribution of the different cognitive components required to accomplish the game tasks. For example, we hypothesized that the time subjects took to complete the first move in a game included time spent encoding that game's search string into memory. Thus, we estimated the contribution of short-term memory to Scavenger Hunt game performance by comparing the distribution of first move times to that of subsequent moves. Similar techniques were used to estimate the contribution of visual search, motor speed, memory retrieval, and cognitive load due to set switching, ultimately giving us useful insights into the cognitive capacity of each user.

Monday, 10:00 (Session C)

The Lognormal Race Model of Choice RT. Andrew Heathcote, *University of Newcastle, Australia* . Ulrich and Miller (1993) considered a model of simple response time (RT) in which activation is accumulated linearly through a cascade of units, with a response being made when activation in the terminal unit reaches a criterion. They showed, assuming IID trial-to-trial variation in the rates and the criterion, that the limiting RT distribution predicted by this type of evidence accumulation model is Lognormal. I propose an extension, the Lognormal Race (LNR) model, which accounts for choice accuracy and RT distribution as the outcome of a race between cascades of linear accumulators corresponding to each possible response. The tractability of this model enables derivation of computationally tractable expressions for the likelihood of correct and error responses for any number of potential choices in the case where trial-to-trial variations in rates are correlated across accumulators. I examine the ability of the LNR model to account for benchmark choice RT phenomena with a focus on the role of rate correlations and their psychological causes.

Monday, 11:50 (Session B)

Generalized Assessment of Divided Attention Through Unobtrusive Monitoring of Computerized Tasks. James McKanna, Holly Jimison, Misha Pavel, *Oregon Health & Science University* . This paper describes a computational modeling effort that is a part of a larger study of elders cognitive functions over time. Here we specifically highlight divided attention, the ability to allocate focus to multiple tasks at once; this is a key cognitive function which decreases with age and which determines performance on a variety of everyday activities like driving. Although there are numerous experimental approaches to the assessment of divided attention, few tools exist to measure it in real life. Accurate measurement of variability in this skill over time, relative to a patient-specific baseline, would allow inference of other forms of cognitive decline, most importantly those leading to Mild Cognitive Impairment or Alzheimer's Disease. In this study, we present a generalizable method for determining relative divided attention ability through analysis of any repeatable, multi-dimensional task. We tested this method

using an adaptive computer game which requires attention in each of two dimensions simultaneously, played by elders at risk for cognitive decline. Each individual players performance was evaluated using two extreme models: a random player and an ideal player. Performance on each of the dimensions was measured during situations of low cognitive load to determine relative attention paid to each aspect of the game; this ratio was then applied to high-load situations to determine total attentional capacity. We will present data from 30 subjects monitored over the course of one year to show the stability of the results over time.

Monday, 9:00 (Session B)

A Rational Model of Attitude Polarization. Adam Darlow, *Brown University* . Lord, Ross and Lepper (1979) first demonstrated attitude polarization when they showed that both students supporting capital punishment and those opposing it became more extreme in their views after reading the same mixed evidence. Many explanations of polarization have been proposed, all of which attribute cognitive or motivational biases to the reader. In this paper, a generative Bayesian model of biased evidence demonstrates that unbiased rational readers can still show polarization if they consider the possibility that the authors are biased. The model assumes that that evidence is sampled from the world, but that authors may use biased sampling procedures that skew the proportion of evidence that supports a claim or opposes it. A reader making inference in this rational model is more likely to attribute bias to an author if they present evidence that is incompatible with their prior beliefs than if they present evidence that is compatible. According to the model, mixed evidence can cause polarization if the mixed evidence is in the form of different authors presenting evidence for different sides of a debate, but not if evidence for both sides is presented by a single author. In addition to polarization, the model also demonstrates non-monotonicity. As the evidence that an author presents becomes more one-sided, it at some point begins to influence the readers opinion less instead of more. Theories of polarization that attribute bias to the reader do not account for non-monotonicity, whereas it follows naturally from a model that attributes the bias to the authors.

Tuesday, 11:10 (Session B)

Developing Knowledge and Probing Its Structure with Primed Lexical Decision. Greg Cox, Richard Shiffrin, *Indiana University* . Both episodic memory and knowledge retrieval are affected by the structure of knowledge at the time of testing. We bring the structure of knowledge under experimental control: Building upon the thesis research of Angela Nelson (2009), we train participants over several weeks to match Chinese characters to themselves, trying to detect slight physical changes (participants have no prior knowledge of Chinese). The characters are presented in pairs, providing the opportunity for associations to form incidentally. Unbeknownst to participants, the pairs are drawn from a set of associative structures, including linear chains of varying length (e.g., A-B-C-D-E) and binary trees. We use primed pseudo-lexical decision to test whether training has produced direct (e.g. A-B) or indirect (e.g. A-C) associations. The task presents a non-diagnostic prime character followed by a test character requiring a decision whether the test character had ever been studied. The relation of the prime to the test character allows the presence of associative structures in knowledge to be inferred. We observe effects of structural distance and number of related associates. Implications for models of knowledge formation and retrieval are discussed. Other transfer tasks involved perception and episodic memory: The results, implications, and relation of these tasks to the lexical decision findings will be discussed as time permits.

Monday, 15:40 (Session B)

How to analyze multifactorial neuroimaging experimental designs with pattern classifiers. Joseph Dunlop, Hervé Abdi, *The University of Texas at Dallas* . Multivariate Pattern Classification Analysis (MVPA) of functional neuroimages has recently advanced rapidly to include new types of classification techniques, such as pattern classifiers used on single factor

designs. Here, we present a new approach which extends these techniques to multifactorial design fMRI neuroimaging experiments. In functional imaging, pattern classifiers identify patterns of brain activation associated with the levels of an experimental factor (e.g., assign scans to some predefined object categories). We evaluate the performance of the classifier for a given subject by assigning new scans to one category. From the classifiers pattern of errors, we compute a category by category distance matrix for each subject, where the entries are d' values (because d' is obtained from error rates, the technique works with any pattern classifier). We analyze the distance matrices using DISTATIS, which is a generalization of MDS. Like MDS, DISTATIS converts the distance matrices to semi-positive definite matrices, which are then integrated into an optimal weighted average called the "compromise." We eigendecompose this compromise into a set of factor scores (representing the coordinates of the categories) and project the subjects matrices onto these factors. In the same factor space, we project linear contrasts representing specific hypotheses, main effects, and interactions. Finally, the reliability and quality of these effects are evaluated using cross-validation and resampling techniques, and expressed as multivariate confidence, tolerance, and prediction ellipsoids.

Monday, 15:40 (Session A)

Rank-Aggregation and Consensus in Ballroom Competition. Royce Anders, William Batchelder, *UC Irvine* . In a large number of situations, items (e.g. competitors, candidates for election, courses of action) are ranked by two or more judges, and an aggregated ranking is desired. There are various algorithmic ways to achieve an aggregated ranking (Borda, Kemeny-Young, Schulze, Skating System methods), however unsurprisingly they do not always produce the same aggregate. This topic is investigated in ballroom dance competitions, characterized by a small number of items (around 6) and judges (5 to 15). Rank aggregation algorithms are often created to handle qualitative differences of experts' beliefs, but in the case of judging performance competitions, one hopes the judges are all using the same set of qualitative schemata for judging. This qualifies the problem as one that Cultural Consensus Theory (CCT) is designed to handle. CCT is a method of aggregating the responses of informants who share a common set of experiences or beliefs. It is in wide use as a tool to determine 'consensus' from small groups in cultural anthropology (e.g. Batchelder & Romney, Psychometrika, 1988; Romney, Weller, & Batchelder, American Anthropologist, 1986). One aspect of CCT is that it provides a statistical measure of whether or not the judges' responses appear to follow from a shared unitary perspective indicating a consensus. This paper compares CCT and a number of the ranking algorithms on a large body of data from ballroom dance competition, both when there appears to be consensus and when there is not.

Sunday, 11:10 (Session B)

How many tools to include into an adaptive toolbox? A Bayesian approach. Benjamin Scheibehenne, Jörg Rieskamp, *University of Basel* . A common assumption within many research areas in psychology is that people possess a repertoire of strategies to solve the problems they face. This strategy repertoire approach, sometimes referred to as an "adaptive toolbox", provides a fruitful way to explain intra- and inter-individual differences in cognitive processes. However, this approach suffers from the problem that the number of assumed strategies is often not constrained a-priori. Thus, a researcher may extend a given toolbox with additional strategies post-hoc to improve the fit to the data. This makes it difficult to rigorously test and compare this class of models. To prevent this problem, a criterion is necessary to decide how many strategies a toolbox should include to describe a given set of choice data. Here, Bayesian statistics provide a useful path to evaluate toolboxes of different size based on their marginal likelihood. The present work illustrates how such techniques can be fruitfully applied within a decision making context. The method we propose is implemented in BUGS language and utilizes

and compares hierarchical models that mimic different cognitive toolboxes. We demonstrate the applicability of our approach by means of parameter recovery studies and based on actual empirical data taken from previously published experiments. The present work also makes the novel contribution of showing how Bayesian techniques can be used to test adaptive toolboxes of various sizes and complexity against alternative decision making theories.

Monday, 9:40 (Session B)

A multivariate hierarchical Bayesian model of confidence and accuracy in probabilistic category learning. Ed Merkle, *Wichita State University*, Matt Jones, *University of Colorado*, Winston Sieck, *Applied Research Associates* . In this talk, we describe a multivariate model that describes the time course of both accuracy and confidence in repeated choice tasks. The modeling framework we develop has interpretable parameters, accounts for individual differences, simultaneously describes growth in confidence and accuracy, describes relationships between confidence and accuracy, and describes differences between experimental conditions. We illustrate the model using data from a probabilistic category learning experiment, in which subjects were asked to distinguish between two artificial diseases based on three binary symptoms. Five experimental conditions were implemented that differed in the learning strategies subjects were directed to use. The model isolates specific effects of the learning strategies on starting points, growth rates, and asymptotes of confidence and accuracy.

Sunday, 16:00 (Session B)

Human recovery of the shape of a 3D scene. Taekyu Kwon, Yun Shi, Tadamasa Sawada, Yunfeng Li, Joseph Catrambone, Stephen Sebastian, Zygmunt Pizlo, *Purdue University* . Our everyday life experience suggests that we are able to form a complete and accurate spatial map of the environment (e.g. an office or a living room) from a single viewing position. This problem is computationally quite difficult because the observer has to reconstruct 3D metric structure of the scene from only one or two perspective images. Furthermore, due to the fact that objects are opaque, the observer can "see" only the front surfaces of the objects (Marr's 2.5D sketch). So how is the observer able to form a complete map of a room, including the back, invisible parts of the objects, the objects that are partially occluded, and the spaces behind the objects? We have already shown that, contrary to Marrs claim, the entire 3D shape, including its front as well as back parts, can be recovered from a single 2D retinal image. The human visual system does it by applying a priori constraints (3D symmetry, compactness and planarity of contours). Once the entire 3D shapes in the scene are recovered, it is possible to recover the spaces between them and form a complete spatial map. In the experiment, subjects viewed a room, containing several pieces of furniture, from a single viewing position, and were asked to draw a top view of the room. The ground truth was established by the PhaseSpace system, whose maximal absolute error in reconstructing positions of 3D points was 2cm. The subjects performance was very accurate and similar to that of a computational model.

Sunday, 15:40 (Session C)

Cognitive Modeling as Derived Measurement. Chung-Ping Cheng, *National Chung Cheng University*, Ching-Fan Sheu, *National Chung Cheng University* . Parameters in the quantitative model of a cognitive process are often interpreted to reflect individual cognitive differences and are compared across groups. Researchers often do not distinguish variables, which are directly observed by apparatus or questionnaire, and parameters, which are indirectly obtained. In the study, a definition of scale type for model parameters is proposed by treating cognitive modeling as a derived measurement. As a consequence, it becomes possible to determine which statistical procedures are appropriate for comparing model parameters across groups. In light of the derived measurement approach, it is shown that parameters of cognitive models, occasionally, may not be quantitative. With illustrative examples from cognitive psychology, we demonstrate how to assign scale types to pa-

rameters of cognitive quantitative models. We also provided justification of the proposal to assign scale type to parameter based on meaningfulness.

Sunday, 15:20 (Session B)

Veridical binocular perception of metric properties of 3D shapes. Yun Shi, Taekyu Kwon, Tadamasa Sawada, Yunfeng Li, Zygmunt Pizlo, *Purdue University* . It has been shown that binocular perception of depth intervals is both inaccurate and unreliable, but that of depth order (called stereoacuity) is extremely reliable. Our recent psychophysical experiments showed, for the first time, that human binocular 3D shape recovery of symmetric polyhedra is extremely reliable and accurate. This contrasts with poor performance of existing models of binocular shape perception, in which the 3D shape is reconstructed from the information about depth intervals. These results strongly suggest that human binocular perception of shape is not based on reconstructing depth intervals. Our new model combines the 3D symmetry prior with the sensory information about depth order of the object points. Specifically, a single 2D orthographic image of a 3D symmetric object determines the 3D shape of this object up to only one unknown parameter, the aspect ratio of the shape. 3D shapes with different aspect ratios are likely to have different depth order of their vertices. The model assumes that the true depth order is known from stereoacuity, and this ordinal information is used to restrict the range of aspect ratios of the symmetric 3D shape. To verify the role of ordinal information about depth in recovering metric 3D shape, we compared the subjects performance in stereoacuity test with that in 3D shape recovery task. Subjects with poor stereoacuity (high threshold) are less reliable in 3D shape recovery task. We conclude by discussing an elaboration of our binocular model so that it does not rely on any depth information at all.

Tuesday, 12:10 (Session A)

A Hierarchical Logistic-Wald Model for the Analysis of Lexical-Decision Data. Mark Andrews, *NTU and UCL*, James Webb, James Webb, *UCL* . In a lexical-decision task (LDT), subjects make speeded responses to whether a letter-string is a word or non-word. LDT is extensively employed throughout experimental psychology, particularly in psycholinguistics. In the typical analysis of LDT data in these contexts, however, accuracy and response latency are analyzed independently, often with aggregation across subjects and/or items. In this work, we present a hierarchical model that accommodates both the coupled nature of latency and accuracy, as well as subject-level and item-level variability in these outcomes. Omittingfull details, if y_{ji} and z_{ji} are respectively the latency and response to the ith word stimulus presented to subject j, we model these as

$$\begin{aligned} y_{ji} &\sim \begin{cases} \mathrm{W}\left(a_0 + b_0\psi_{ji}, \lambda_0, \theta_0\right), \text{if } z_{ji} = 0, \\ \mathrm{W}\left(a_1 + b_1\psi_{ji}, \lambda_1, \theta_1\right), \text{if } z_{ji} = 1, \end{cases} \\ z_{ji} &\sim \mathrm{Bernoulli}\left(p_{ji}\right), \\ p_{ji} &= \mathrm{logit}^{-1}\left(a_z + b_z\psi_{ji}\right), \end{aligned}$$

where $\mathrm{W}\left(\mu, \lambda, \theta\right)$ denotes a Wald distribution with mean μ, shape λ and offset θ. Here, ψ_{ji} is a latent-variable that is a subject-varying function of lexical items, i.e. $\psi_{ji} = \alpha_j + \beta_j^{\mathrm{T}} x_{ji}$, where $x_j i$ denotes the values of relevant lexical-variables of stimulus ji, and α_j and β_j are drawn from drawn from common subject-wide distributions. Using a large LDT data-set, we compare this model with the more standard methods of analyzing the roles of variables (frequency, length, orthographic regularity, etc) on lexical processing. We demonstrate how the coupled-outcome hierarchical model can considerably clarify, while the non-hierarchical independent analysis can often distort, the roles of these lexical variables.

Monday, 15:20 (Session B)

Distance-based Partial Least Squares Regression (DISPLS): A new approach to relate distances in psychology and neuroimaging. Anjali Krishnan, *The University of Texas at Dallas*, Nikolaus Kriegeskorte, *University of Cambridge*, Hervé Abdi, *The University of Texas at Dallas* . How do we perceive the world? One possible explanation is that the brain associates semantic (high-level)

information with perceptual (low-level) information. Researchers have tried to detect this semantic information through various behavioral, neuroimaging, and computational approaches. A common feature of these approaches is the notion of distance, which quantifies similarity (or dissimilarity) between stimuli. We could use distances between stimuli based on their perceptual features to predict distances between the same stimuli based on behavioral or neural measures. The prediction could be interpreted as the low-level information encoded in the brain, which we obtain from the stimuli. The residual of the prediction could be interpreted as the high-level information encoded in the brain, which we do not obtain from the stimuli. Our research question involves prediction, but standard methods used to analyze distances such as multidimensional scaling and procrustes analysis are not predictive. Partial Least Squares Regression (PLSR) is a method that can predict a set of dependent variables from a set of independent variables, but PLSR does not analyze distances. We propose a new statistical method called Distance-based Partial Least Squares Regression (DISPLS), which predicts distances from distances. We illustrate DISPLS with data provided by Nikolaus Kriegeskorte, which were collected on humans (fMRI) and monkeys (single-cell recordings). We will show how DISPLS could model what the brain encodes as the sum of the low-level information predicted by stimuli and the high-level information unique to the brain and also show how this information could be preserved across species.

Monday, 12:10 (Session A)

Estimating Individual Differences in a Rational Model of Memory. Pernille Hemmer, Mark Steyvers, *UC Irvine* . Previous research has shown that people can incorporate prior knowledge when recalling events from episodic memory. Our earlier modeling work has explained effects of prior knowledge with a rational model of memory. In this approach, it is assumed that individuals solve the computational problem of memory recall (what was the original stimulus shown?) by optimally combining the available information from episodic memory and prior knowledge. In this work, we extend these rational models of memory by incorporating individual differences. We assume that individuals can have varying internal noise levels and also different subjective priors. We estimate these individual differences using a Bayesian data analysis applied to the rational model. Therefore, in this approach, we combine two different kinds of Bayesian analysis. From the perspective of the individual performing the task, we use a Bayesian analysis to motivate a rational model of memory. From the perspective of the experimenter, we use the outcome of this Bayesian inference as a forward (generative) step to analyze the observed data in the experiment. We illustrate this approach with an empirical study in which people recall the height of females, males and ambiguous silhouettes.

Monday, 12:10 (Session C)

Learning of dimensional biases in human categorization. Adam Sanborn, *University College London*, Katherine Heller, *University of Cambridge*, Nick Chater, *University College London* . Existing models of categorization typically represent to-be-classified items as points in a multidimensional space. While from a mathematical point of view, an infinite number of basis sets can be used to represent points in this space, the choice of basis set is psychologically crucial. People generally choose the same basis dimensions, and have a strong preference to generalize along the axes of these dimensions, but not 'diagonally'. What makes some choices of dimension special? We explore the idea that the dimensions used by people echo the natural variation in the environment. Specifically, we present a rational model that does not assume a particular basis, but learns the same type of dimensional generalizations that people display. This bias is shaped by exposing the model to many categories with a structure hypothesized to be like those which children encounter. The learning behavior of the model captures the developmental shift from roughly 'isotropic' for children to the axis-aligned generalization that adults show.

Tuesday, 10:50 (Session B)

Modeling knowledge formation and frequency effects in lexical decision. Angela Nelson, *UCSD*, Richard Shiffrin, *Indiana University* . In this talk we present work from two previous studies showing the effects of differential training experience on novel items in a pseudo-lexical decision task. The first experiment uses a training paradigm in which contextual information plays a large role in knowledge development and varies based on item frequency; the second experiment however trains all items in a relatively context-free environment. Training frequency is shown to play a large role in the pseudo-lexical decision task for both experiments, including (in the second experiment) when subjects are re-tested after a six-week delay: high frequency items are always recognized more quickly and more accurately than low frequency items. Given that contextual information during training only varied based on frequency in experiment 1 an explanation of these effects based on context alone would not predict the results seen in experiment 2. We present a portion of the SARKAE model that accounts for the development of knowledge during the two types of training and the use of that knowledge in the pseudo-lexical decision task. The model is able to successfully account for the results shown in both experiments 1 and 2.

Tuesday, 11:30 (Session A)

Semantic Associates in Motherese: Comparing the Associative Structure of Adult and Child-directed Speech with Graph Analysis. Thomas Hills, *University of Basel* . Does child-directed speech reveal transitional probabilities consistent with a more 'free associative' speech pattern than adult-directed speech? If so, this associative motherese would help explain why associates predict order of acquisition in early word learning, and provide clues to a cognitive process that would generate motherese and possibly facilitate learning. To test the main question, semantic space representations based on word co-occurrences were computed using language corpora from adult-directed and child-directed speech. These representations were then compared with a free association network consisting of the same subset of words. The analyses computed graph similarities based on edit-distance and compared other statistical properties of the whole networks. Early and late learned words were also analyzed for their statistical properties in the two representations. The results revealed statistical properties of the early language environment that may be consistent with an associative structure in child-directed speech.

Sunday, 15:20 (Session C)

Questionnaire data are linear enough: Inferences about interactions based on polytomous items. Annemarie Zand Scholten, Denny Borsboom, *University of Amsterdam* . Interaction effects found on psychological ability tests can be at risk for invalid inference under specific circumstances. Although these circumstances are not extremely frequent, they do occur regularly in experimental psychology and cannot always be avoided. Critical factors are very high (or low) test difficulty, high item discrimination, long tests, large effect size and small sample size. These factors, however, have shown to increase the risk of ambiguous results for dichotomous items only. With a simulation study we show that when items are polytomous, risk of inferential error much smaller. The graded response model was used to simulate data. If the relationship between an underlying quantitative variable and observed data can be described by such a model, questionnaires using three or more response categories will be relatively safe from inferential error concerning interactions due to arbitrary choice of measurement scale.

Sunday, 11:30 (Session B)

Judgment Field Theory: A computational model of subjective probabilities. Timothy Pleskac, *Michigan State University* . Psychological theories of subjective probability judgments (SPs) typically assume that accumulated evidence (support) mediates the relationship between the to-be-judged event and the SP (e.g., Tversky & Koehler, 1994). To model the

time course of this evidence accumulation I have integrated decision field theory's (DFT; Roe, et al., 2001) dynamic network of attribute processing with Pleskac and Busemeyer's (in press) diffusion model of confidence. The model–judgment field theory (JFT)–treats events (Lance winning a bicycle race) as composed of a set of attributes (Lance's climbing and sprinting ability). During deliberation, attention shifts between the attributes. At each moment, the attended-to-attribute results in a level of evidence supporting each event in the evaluation set relative to the remaining events, which is then accumulated. Markers–one for each estimate–are placed across the evidence space. When evidence passes a marker there is a probability the judge stops and gives the respective estimate. The markers are positioned with the starting point of evidence accumulation resting at the ignorance prior probability. JFT offers a single process account of effects due to a bias towards an ignorance prior; why binary complementarity of SPs occurs; and why subadditivity of packed hypotheses occurs. JFT also makes new predictions regarding how the events in the evaluation set can interact to produce violations of independence. More generally, JFT in combination with DFT offers a single process account for judgment and decision making rather than a process for judgment and a process for decision.

Sunday, 10:00 (Session B)

Linking Learning to Looking: Model Selection for Eye Movements. Daniel Yurovsky, *Indiana University*, Shohei Hidaka, *Japan Advanced Institute of Science*, Chen Yu, Linda Smith, *Indiana University* . Because eye fixations are produced rapidly in response to stimuli, gaze patterns can be a particularly sensitive tool for measuring learning. Unfortunately, inferring learning from looking in many tasks is anything but straightforward – especially when no other measures provide convergent evidence. This problem is particularly vexing for investigators studying development, for whom eye movements are often the only available source of information about learning. As a result, researchers often adopt vague – and occasionally ad hoc – metrics for linking learning to looking. But, when data is sparse and linking functions are imprecisely specified, conclusions are hotly debated and failures to replicate are common. We propose a model selection framework for choosing explicit linking hypotheses in a formal, consistent manner. The entire set of eye movements generated by a participant performing a learning task is treated as a time-series. Candidate models are then assigned likelihoods in proportion to their probability of generating these time-series. We validate this approach by determining its rate of false alarms using a null generating process, and then apply it to two different infant learning paradigms—statistical word-learning (Smith & Yu, 2008) and cued attention (Wu & Kirkham, accepted). In each case, our framework allows us to make principled inferences about what (and how) each infant learns.

Tuesday, 11:50 (Session C)

Explaining Order Effects. The Belief-Adjustment Model Versus The Quantum Inference Model. Jennifer Trueblood, Jerome Busemeyer, *Indiana University* . Order of information plays a crucial role in the process of updating beliefs across time. Specifically, an order effect occurs when probability judgments are influenced by the order of a series of information. These order effects are non-Bayesian by nature and are difficult to explain by classical probability models. We use the empirical results of a jury decision-making task conducted by McKenzie et al. (2002) to motivate the development of a quantum inference model for order effects. The quantum model is derived from the axiomatic principles of quantum probability theory and provides a more coherent explanation of order effects than heuristic models such as the belief-adjustment model (Hogarth and Einhorn, 1992). To further test the quantum inference model, a new jury decision-making experiment is developed. This experiment extends the work of McKenzie et al., and the results are used to compare the quantum model to the belief-adjustment model. Specifically, we compare the quantum inference model to two versions of the

belief-adjustment model, the adding model and the averaging model. We show that both the quantum model and the adding model provide good fits to the data. To distinguish the quantum model from the adding model, we develop a new experiment involving extreme evidence. The results from this new experiment suggest that the belief-adjustment model faces limitations when accounting for tasks involving extreme evidence whereas the quantum inference model does not.

Tuesday, 15:40 (Session B)

A distributed representation of internal time leads to scale invariant timing behavior. Karthik Shankar, Marc Howard, *Syracuse University* . We present an extension to the temporal context model (TCM) that explicitly stores temporal information about when a stimulus was encountered in the past. The temporal information is constructed from a set of temporal context vectors adopted from TCM. We show that an array of temporal context vectors with different time constants is closely related to the Laplace transform of real time events. A simple excitatory/inhibitory band of feedforward connections from the array of temporal context vectors is sufficient to approximately reconstruct the timing information contained in the array of temporal context vectors. The reconstruction procedure has the property that the reconstructed timing of events further in the past is less accurate than the reconstructed timing of more recent events. We show formally that the procedure yields the scalar property in the variability of the underlying timing distribution. This mathematical property leads to wide-ranging implications for a variety of paradigms. We show that it leads naturally to explain the scalar property widely-observed in timing paradigms. It also accounts for the lack of a temporal scale in associative learning. Ongoing work suggests that this formalism can be adopted to a wide range of phenomena potentially leading to a unified theory of recency and contiguity in episodic memory and timing phenomena.

Tuesday, 10:00 (Session B)

The Contribution of Study-Test Lag to Old Item Variability in Recognition Memory. Melissa Prince, Andrew Heathcote, *The University of Newcastle* . Accounts of recognition memory data are often based on signal detection models, where studied (old) and unstudied (new) items are represented as two Gaussian distributions located on a single memory strength dimension. It is commonly found that the old distribution is more variable than the new (i.e., zROC slope=0.8). Ratcliff, Sheu and Gronlund (1992) suggested that this greater variance might in part be due to variations in the time between study and test (lag) among old items. We tested this explanation by manipulating variability in lag by varying (between-subjects) the order in which study items were tested, such that lag variability was (a) minimised by testing items in the same (Forward) order as their study presentation or (b) maximised by testing in the reverse (Backward) order. Although the lag standard deviation differed by a factor of more than 4 between these conditions, maximum likelihood ROC analysis of each participants confidence ratings revealed only slightly greater variability for old items in the Backward compared to the Forward condition. These results suggest that, at least for the shorter (32 item) study lists used in our experiment, lag variation is at best a minor source of old-item variability in memory strength, despite the old item standard deviation being 1.4 times the new item standard deviation. We will also report results from a follow-up experiment with an improved effect size (by increasing list length) and improved power (by using a within-subjects manipulation of lag variability).

Tuesday, 16:00 (Session A)

Models of Information Integration in Perceptual Decision Making. Jared Hotaling, *Indiana University*, Andrew Cohen, *University of Massachusetts*, Jerome Busemeyer, Richard Shiffrin, *Indiana University* . In cognitive science there is a seeming paradox: On the one hand researchers studying judgment and decision making (JDM) have repeatedly shown that people employ simple and often sub-optimal strategies when integrating information from multiple sources. On the other hand another set of researchers has

had great success using Bayesian optimal models to explain information integration in fields such as categorization, perception, and memory. One impediment to reconciling this paradox lies in the different experimental methods each group has used. Recently, Hotaling, Cohen, Busemeyer, & Shiffrin (submitted) conducted a perceptual decision making study designed to bridge this methodological divide and test whether the sub-optimal integration found in verbal problems stated in terms of probabilities may also appear in perceptual tasks. Their results indicate that a classic JDM finding, the dilution effect, does arise in perceptual decision making. Observers were given strong evidence X favoring A over B, and weak evidence Y also favoring A over B. According to Bayesian analysis, the odds in favor of A should be multiplied, resulting in an increased likelihood of A. Instead, Hotaling et al. found that the weak evidence diluted the strong evidence, producing decreased judgments and choice probabilities favoring A, given X & Y, than given X alone. I review these empirical findings and test both rational and cognitive models of the integration process.

Tuesday, 11:10 (Session C)

Mathematical Expectation of Threat, Unpredictability, and Mechanisms of Stochastic "Faint Threat" in a Model of Decisional Control. Matthew Shanahan, Richard Neufeld, *The University of Western Ontario* . This presentation addresses issues involved with calculating mathematical expectation of threat $E(t)$ in the context of a normative model of decisional control (Shanahan & Neufeld, 2010, BJMSP). Three choice conditions are possible for the decision maker (DM) at each level of a bin-model prototype of a successive-nesting decisional hierarchy: decision-making done by the DM (free choice - C), external selection revealed to the DM (no choice - N), or external selection not revealed to the DM (uncertainty - U). Scenarios are named by nodal choice condition in increasing order of nesting (e.g., CNU denotes a C condition for bin sets, nesting an N condition for bins, in turn nesting a U condition for threat-embedding elements). Within this general architecture, a formalized syntax for the expression of $E(t)$ discloses consistent family groupings paralleling the progression of $E(t)$ values, of which the hierarchical positioning of U is a principal determinant. Marked elevation in $E(t)$ accompanies U's position at a more subordinate level of the hierarchy. Such elevation analytically is shown to emanate from nuanced mechanisms of bin-element access. In addition, uncertainty as 'information withheld' is mathematically distinguished from uncertainty as 'event unpredictability'. Potential implications of uncertainty reduction for clinical stress management are discussed.

Tuesday, 16:00 (Session B)

Rats, non-rewards, and decaying uncertainties. Chloe Bracis, James Anderson, *University of Washington*, Andrew Goodwin, *Environmental Laboratory, ERDC* . Phenomena such as extinction and spontaneous recovery are found in both Pavlovian conditioning and instrumental learning. While changes in response rate reflect the animal's changing expectation of reward, only Pavlovian conditioning provides clear events to update expectation in response to no reward. Here we take a mathematical learning model (Anderson et al. CogSci 2010), which operates in event time, that has been used to successfully model these phenomena in Pavlovian conditioning experiments and apply it in an instrumental learning context. The model tracks distal and proximal scales of the expected interval to reward as well as their respective errors in order to combine both estimates through their uncertainties. We handle updating expectations recursively throughout the interval for non-rewards, translating non-events from real time into an event time characteristic of Pavlovian models. Additionally, the model translates between real time and event time to decay uncertainties between sessions; this reverts expectation to the long-term mean when there is no information, giving rise to spontaneous recovery. We present examples of fitting the model to data and demonstrate how the underlying model dynamics give rise to the observed behavior. This

model synthesizes time and event domain rewards into a common framework.

Sunday, 11:50 (Session A)

Reward maximization, drift-diffusion and inter-response times in instrumental conditioning. Patrick Simen, Fuat Balci, *Princeton University*, David Freestone, *Brown University* . Drift-diffusion models account for the complete shape of response time distributions in perceptual decision making experiments. In tasks involving rewards as feedback, fitted model parameters have been shown to adapt during performance so as to maximize reward rates. We now show that a diffusion model with drift equal to a simple function of reward rate also captures the shape of inter-response time distributions from mice and rats in simple conditioning tasks—tasks in which the time between rewards, and not any other perceptual signal, is the critical independent variable. This model furthermore provides a novel account of hyperbolic response rates as a function of reinforcement rates in variable interval tasks, and of states of either rapid or infrequent responding in fixed interval tasks. Fixed-interval state transitions are triggered by a hierarchically superior interval timer, which is itself a drift-diffusion process with parameters tuned to maximize response time precision. With this tuning, the high-level timer in the model accounts for the law of scalar invariance in interval timing. These results suggest that simple processes of noisy accumulation, governed by reward-sensitive feedback controllers, play critical roles in response generation across a wider range of behaviors than has previously been hypothesized.

Monday, 16:40 (Session B)

Calculating Prediction Intervals for Future Performance. Kelly Addis, Michael Krusmark, Tiffany Jastrzembski, Kevin Gluck, *Air Force Research Laboratory*, Stuart Rodgers, *AGS TechNet* . The Predictive Performance Optimizer (PPO) is a cognitive tool designed for learners and trainers to track knowledge and skill change, and to quantitatively predict performance at specified future points in time. PPO functions according to an underlying mathematical model, based on an extension of the General Performance Equation (Anderson & Schunn, 2000), that accounts for stability of knowledge and skill levels by accounting for the temporal distribution of training events. It calibrates learning and decay parameters to a learners unique training history, and predicts performance at future time-points based on those parameters. In its current form, PPO generates point predictions which estimate specific levels of performance at specific points in time. We know, however, that human behavior varies over time, and that model precision generally decreases with longer lead times. It would therefore be useful for trainers to have a measure of this uncertainty so that more informed training decisions can be made. We are exploring two methods for computing prediction intervals to provide this additional information. The first method adds variability into the learning and decay parameter estimates to produce a range of predicted performance. The second method extrapolates future residuals from the known residuals of the data that the model was calibrated against. Both methods have positive and negative characteristics, which will be detailed in the presentation. Although incorporation of prediction intervals into a non-stochastic model such as ours is not straightforward, it is an important step in developing PPO into a useful tool for learners and trainers.

Monday, 15:20 (Session A)

Averaging and Choosing in the Mind: Should Judgments Be Based on Exemplars, Rules or Both? Bettina von Helversen, Stefan Herzog, *University of Basel* . When judging or categorizing objects people may rely on different kinds of cognitive processes with similarity-based and rule-based processes being the most prominent processes under discussion (Ashby, Alfonse-Reese, Turken, & Waldron, 1998, Psych. Review). Models assuming that both types of processes are used, often also assume that one process is chosen, depending on the success with which the process can solve the task (e.g.

Ashby et al., 1998). However, machine learning and group decision making research suggests that when two judgments are available, it is often better to take the average of the two than to choose one of them—particularly when errors are somewhat independent and there is uncertainty about which judgment will be more accurate (Soll & Larrick, 2009; JEP: LMC). In a simulation study we investigated in five real world environments whether judgment accuracy was higher if (a) an exemplar-based or (b) a rule-based strategy was chosen or when (c) their predictions were averaged. Our cross validated results show that (except for very small samples) averaging is more accurate than choosing only a rule-based strategy or an exemplar-based strategy, choosing the strategy which performed better in the training sample (based on its BIC) and as good as perfectly knowing which strategy will be more accurate in hindsight. These results suggest that averaging may be a successful mechanism within one mind.

Monday, 10:50 (Session C)

A particle filter account of multi-alternative decisions. Guy Hawkins, Scott Brown, *University of Newcastle*, Mark Steyvers, *University of California Irvine*, Eric-Jan Wagenmakers, *University of Amsterdam* . Most choice response time research has focused on binary decision making. When there are more than two choice alternatives the typical result is Hick's Law, that response time and the logarithm of the number of choice alternatives are linearly related (Hick, 1952). We recently reported results from two experiments that did not conform to Hicks Law for decisions between many choice alternatives, suggesting a limit to Hick's Law. Rather than using the typical evidence accumulation framework, we propose an alternative model based on capacity limitation. Our particle filter account is capable of predicting Hick's Law, consistent with existing multi-alternative choice models, as well as the violations of Hick's Law observed in our data sets all with the manipulation of a single parameter: number of particles. The number of particles is interpretable as the quantity of resources a decision maker allocates to a decision task. An observers resources must be divided amongst possible response alternatives, thus resulting in a decreasing number of particles per choice as the number of response alternatives increases. This proposal predicts Hick's Law for a model endowed with many particles, consistent with the notion of Hick's Law as an account of statistically optimal decision making. With few particles response time and accuracy predictions depart from Hick's Law but are consistent with our data sets and the notion of humans as limited capacity observers.

Tuesday, 11:50 (Session A)

Modeling the Acquisition of the Mental Lexicon. George Kachergis, Chen Yu, Richard Shiffrin, *Indiana University* . Several studies have found that adults can acquire word-referent pairings after experiencing a series of individually-ambiguous trials (i.e., trials containing multiple words and referents). To disambiguate pairings – which many learners do with great success – word-referent co-occurrences must be integrated across trials. We discuss a variety of factors that have empirically been found to affect learning performance, such as pair frequency, pairs per trial, temporal contiguity, and contextual diversity (how many pairs a given pair appears with during training). Using this data, a variety of associative models were constructed, implementing diverse attention, memory, and inference mechanisms. We find that some surprising empirical results (e.g., a null frequency effect when pairs of different frequency co-occur) can be explained by shifting attention and limited memory. Finally, we demonstrate that although learners do assume mutually exclusive pairings in some situations (to their great advantage), they can also relax this assumption and learn more complex mappings.

Monday, 11:30 (Session C)

Discovering Structure by Learning Sparse Graphs. Brenden Lake, Joshua Tenenbaum, *Massachusetts Institute of Technology* . Systems of concepts such as colors, animals, cities, and artifacts are richly structured, and people discover the structure of these domains

throughout a lifetime of experience. Discovering structure can be formalized as probabilistic inference about the organization of entities, and previous work has operationalized learning as selection amongst specific candidate hypotheses such as rings, trees, chains, grids, etc. defined by graph grammars [Kemp & Tenenbaum, 2008, 116(1), 20-58]. While this model makes discrete choices from a limited set, humans appear to entertain an unlimited range of hypotheses, many without an obvious grammatical description. This structural flexibility is crucial for learning about domains that are interestingly structured but lack an obvious structural grammar, such as artifacts and social networks. In this paper, we approach structure discovery as optimization in a continuous space of all possible structures, while encouraging structures to be sparsely connected. When reasoning about animals and cities, the sparse model achieves performance equivalent to more structured approaches. We also explore a large domain of 1000 concepts with broad semantic coverage and no simple structure.

Monday, 11:10 (Session C)

Feature learning as nonparametric Bayesian inference. Joseph Austerweil, Thomas Griffiths, *UC Berkeley* . A fundamental problem faced by cognitive systems is the formation of basic units to represent observed objects. The computational problem of feature learning has two major facets: (1) any object can be represented by an infinite number of features and (2) the feature representation for an object depends on its context. In both perception (e.g., Kanisza, 1975) and categorization (e.g., Wisniewski & Medin, 1994), people flexibly use different feature representations for the same object in different contexts. We argue that these two facets of human feature learning are interdependent, complementary and arise out of a rational solution to the computational problem. We present a nonparametric Bayesian model for feature learning that finds the best feature representation for a set of objects out of an infinite set of possible features. Any object can be represented by an infinite number of features over all contexts it can be in; however, in any particular context, the object has a finite number of features. This is crucial because it allows the feature representation of an object to change appropriate to its context, but the inference for features of an object remains tractable. The model predicts that the same object should be represented as a whole or a conjunction of parts depending on the distribution of parts in its context (parts co-vary yields a whole; parts independent yields the parts as features). We confirm this prediction in a series of experiments using perceptual objects (2-d objects and 3-d rendered objects) and concepts (novel animals).

Sunday, 16:00 (Session C)

A Three-Parameter Item Response Model of Matching. Matthew Zeigenfuse, William Batchelder, Mark Steyvers, *University of California, Irvine* . In a common experimental paradigm, participants are shown two lists of items of equal length and asked to associate each element of the second list with exactly one element of the first. Often in such experiments, we would like to draw conclusions regarding both a participant's ability in the domain from which the list items were drawn as well as the difficulty and discriminability of each item. A common type of measurement model for these quantities is Item Response Theory (IRT); however, the application of IRT requires that a participant's responses on the items be conditionally independent given the participant and item parameters, a property known as local independence, which is clearly violated for the matching experiment. In this talk, we present a novel extension to traditional IRT which is able to resolve this apparent incompatibility. We provide illustrations of model performance on both simulated and actual data.

Monday, 16:20 (Session B)

Measuring abnormality in neuropsychological deficits using generalized linear mixed models. Rainer Stollhoff, *MPI for Mathematics in the Sciences* . Neuropsychologists often have to assess whether a patient's performance in one or more behavioural tests devi-

ates fundamentally from that of a control population. A commonly used method is to select for each individual a control population that is matched in terms of possible contributing factors (age, gender, education, ...), calculate mean and standard deviation of the matched controls, and derive an abnormality score based on an appropriate test statistic (e.g. z-score, modified t-test). Shortcomings of this method are a reduction in the number of available control samples due to the matching process and - in the case of continous contributing factors - a somewhat arbitrary discretization of a continuous variable into intervals (e.g. age is discretized into age-bands). Furthermore, while most test statistics used assume a normal distribution experimental test results are often non-normal. Generalized linear mixed models (GLMMs) can be used to alleviate these difficulties and construct continuous abnormality scores. Matching can be achieved by a regression of test scores on continuous contributing factors, and the generalization to exponential family distributions allows to calculate abnormality scores for non-normal test scores. Methods to derive abnormality scores and diagnostic rules based on GLMMs will be presented and discussed. Furthermore, a demonstration of the methods will be given for the case of diagnosing prosopagnosia, a deficit in facial identification, based on individual performance profiles obtained in several face recognition tests.

Monday, 11:50 (Session C)

Hierarchical Approximate Bayesian Computation. Brandon Turner, Trisha Van Zandt, Mario Peruggia, *Ohio State University* . A natural modeling framework for the study of individual and group differences is provided by Bayesian hierarchical models. However, some models have likelihoods that have proved to be computationally intractable or difficult to fully implement. This has motivated the use of Approximate Bayesian Computation (ABC). In ABC, the computation of the likelihood function is replaced by a simulation of the model. After simulation of the model, a distance metric is computed between the simulated data and the observed data. This distance is then compared to a decreasing series of "acceptance" criteria. One important model that is easy to simulate but has a difficult likelihood function is the Wiener diffusion process for two-choice decisions. We used an ABC method to fit a Bayesian hierarchical version of the diffusion model. We first refined the technique by fitting data from a simulation study, and then we fit the model to real data. The data were collected in a perceptual-matching task that varied the discriminability between same/different pairs as well as instructions that emphasized either speed or accuracy of responding. We discuss the ease and accuracy of the ABC approach, as well as its utility as compared to other methods for model fitting.

Sunday, 9:40 (Session B)

Adaptive Strategy Choice in Cognitive Diagnosis: An Application to Fraction Subtraction. Yun Jin Rho, James Corter, Matthew Johnson, *Teachers College, Columbia University* . Problem solvers who know several different solution methods or strategies for a problem may choose a strategy flexibly for each problem in order to lessen cognitive load or to maximize accuracy of performance under time pressure. This idea is explored, and consideration is given to how this issue of multiple-strategy use will affect cognitive skill diagnosis. The adaptive strategy choice hypothesis is proposed, which states that if test takers know more than one solution strategy, they will tend to choose the easiest effective strategy for a particular problem. This idea is applied to a well-known problem-solving domain—that of mixed-fraction subtraction. In this domain, adaptive strategy choice leads to a hybrid strategy (Method C) in addition to the previously recognized Methods A and B (Method A: first convert mixed numbers to improper fractions; Method B: first separate mixed numbers into integer and fraction; Tatsuoka, 1990). The idea of Method C is that people can select strategies on each item, using whichever strategy is easier between Method A and B. Previous cognitive diagnosis for mixed fraction subtraction has paid more attention on Method B because of better model fit than Method A. However, the present

results from multiple regression and mixed effects logistic regression analyses show that Method C works better than Method A or B to predict the item difficulties. In addition, Method C shows the best model fit among the three methods under the NIDA (Noisy inputs, deterministic and gate) model.

Monday, 16:00 (Session A)

The Wisdom of Crowds in Solving Bandit Problems. Shunan Zhang, Michael Lee, *UCI* . The "wisdom of the crowds" refers to the idea that the aggregated performance of a group of people on a challenging task may be superior to the performance of any of the individuals. For some tasks, like estimating a single quantity, it is straightforward to aggregate individual behavior. For more complicated multidimensional or sequential tasks, however, it is not so straightforward. Cognitive models of behavior are needed, to infer what people know from how they behave, and allow aggregation to be done on the inferred knowledge. We provide a case study of this role for cognitive modeling in the wisdom of crowds, using a multidimensional sequential optimization problem, known as the bandit problem, for which there are large differences in individual ability. We show that, using some established cognitive models of people's decision-making on these problems, aggregate performance approaches optimality, and exceeds the performance of the vast majority of individuals.

Monday, 9:40 (Session C)

The Statistical Properties of the Survivor Interaction Contrast. Joseph Houpt, James Townsend, *Indiana University* . The Survivor Interaction Contrast (SIC) is a powerful tool for assessing the architecture and stopping rule of a model of mental processes (Townsend and Nozawa, 1995). Despite its demonstrated utility, the methodology has lacked a method for statistical testing until now. We will briefly describe the SIC then develop some basic statistical properties of the measure. These developments lead to a statistical test for rejecting certain classes of models based on the SIC. We verify these tests using simulated data, then demonstrate their use on data from a simple cognitive task.

Tuesday, 15:40 (Session C)

A Bayesian model of judgment revisions in a social setting. Sven Stringer, *University of Amsterdam*, Mark Steyvers, *University Of California, Irvine* . Estimating quantities can be a difficult task. Especially if other people have different opinions. We studied how anonymous others influence initial estimates of participants. In this talk we present a Bayesian model of such a revision process. We will also look at individual factors that might play a role in the revision process.

Sunday, 9:40 (Session C)

Concensus among Concensus Methods. Anna Popova, Michel Regenwetter, Sergey Popov, *UIUC* . Social choice theory in Economics and Political Science has highlighted that competing notions of rational social choice are irreconcilable, because of impossibility theorems and computer simulations. Do concensus methods disagree so much in reality? We report on a behavioral social choice comparison of Condorcet, Borda, Plurality, Negative Plurality, STV, Coombs, and Plurality Runoff one, using several data sets from American Psychological Association presidential elections. The empirical findings contradict theoretical expectations. Behavioral research in social choice may reveal many future surprises. Explaining the empirical agreement among social choice outcomes is an open problem (Regenwetter, 2009, Perspectives on Psychological Science).

Tuesday, 10:50 (Session C)

Structure from Sequence: A Nonparametric Bayesian Analysis of Human Sequence Learning. Jerad Fields, Todd Gureckis, *New York University* . Discovering the latent structure underlying sequential information is a problem that is central to many aspects of human cognition (e.g., language, perception). In this talk, we describe a new account of human sequence learning based on the principle of Bayesian model comparison. The model uses nonparametric Bayesian inference techniques to

infer a distribution over possible hidden Markov model (HMM) structures that are consistent with a particular training sequence. We successfully apply the model to a number of well known findings in artificial grammar learning (AGL) tasks (e.g., Gomez, 2002). Finally, we describe a novel AGL experiment which explicitly differentiates our account from more traditional approaches. In contrast to accounts based on associative learning principles (e.g., Simple Recurrent Networks), we argue that human sequence learning is better explained as a structured inference process that reflects the uncertainty over candidate structures.

Tuesday, 16:20 (Session B)

Regularities in Dream Social Networks. Richard Schweickert, *Purdue University*, Charles Viau-Quesnel, *Laval University*, Zhuangzhuang Xi, Hye Joo Han, *Purdue University*, Claudette Fortin, *Laval University* . Social networks in waking life are complex, but tend to have regularities such as a power law degree distribution. An individuals memory for people and their relations presumably represents these regularities. When an individual is in REM sleep, primary sensory cortices are blockaded, so there is little input from the outside world. It is reasonable to conclude that any regularities that appear in dream content arise from corresponding regularities in the dreamers memory. Social networks were constructed for characters in dreams in a series from the same dreamer. Considerable regularity appears; for example, the largest eigenvalues of the adjacency matrix follow a power law.

Sunday, 12:10 (Session C)

Matching Regularity for 2D Shapes and Locations. Lacey Perry, Ehtibar Dzhafarov, *Purdue University* . The general definition of well-matched regular stimulus spaces is given in Dzhafarov & Dzhafarov (2010, *Theoria*, 76, 25-53). When applied to pairwise presentation of stimuli in two fixed observation areas (e.g., one on the left, one on the right), the notion implies that (1) for every stimulus x one can find a stimulus y in another observation area such that x and y match each other; and (2) if an x matches both y and y', then y and y' are equivalent (in the sense of always matching or not matching any stimulus together). This property has nontrivial consequences for several issues, ranging from the ancient "sorites" paradox to modeling of discrimination by means of Thurstonian-type models. We have tested the regular well-matchedness hypothesis for locations of two dots within two side-by-side circles, and for two side-by-side "flower-like" shapes, each described by $R+K_a\cos a\theta+K_b\cos b\theta$ in polar coordinates. In the location experiment the coordinates of the dot in one circle were adjusted to match the location of the dot in another circle. In the shape experiment the amplitudes K_a, K_b of one shape were adjusted to match the other shape. The adjustments on the left and on the right alternated in long series according to the ping-pong matching scheme developed in Dzhafarov (2006, *Journal of Mathematical Psychology*, 50, 74-93). The statistics of the adjustment series have been found to be in a good compliance with the regular well-matchedness hypothesis.

Sunday, 10:00 (Session C)

Symmetry-Based Methodology for Decision-Rule Identification in Same-Different Experiments. Alexander Petrov, *The Ohio State University* . The standard practice to reduce every same-different data set to two numbers (hits and false alarms) is wasteful because the response pattern to all four stimulus pairs carries information about the decision rule adopted by the observer. We describe eight rules organized in three families: differencing, covert classification, and likelihood ratio. We prove that each family produces a characteristic pattern of (in)equalities among the response probabilities. The basic idea of the proof is that symmetric decision boundaries demarcate symmetric response regions, the perceptual distributions have (mutually) symmetric probability density functions, and the integrals of symmetric densities over symmetric regions are equal. On this basis, we propose two simple but powerful qualitative tests for same-different data analysis. Is the performance on stimulus pairs

AA and BB statistically indistinguishable? If not, differencing and likelihood-ratio strategies can be rejected. Is the performance on pairs AB and BA indistinguishable? If not, covert classification can be rejected. We present algorithms (and Matlab software) for fitting two covert-classification models and illustrate the new methodology in a perceptual learning experiment on visual motion-direction discrimination. The standard assumption of symmetric decision criteria was violated.

Sunday, 9:20 (Session B)

Adaptive Optimal Inference and Feedback for Numerical Representational Change. Yun Tang, Christopher Young, Jay Myung, Mark Pitt, John Opfer, *The Ohio State University* . We explore an adaptive design optimization approach for optimizing experimental designs to discriminate mathematical models of childrens number concepts. Studies on the development of numerical representations typically find that young children initially estimate numerical magnitudes to increase logarithmically with actual value before later learning the decimal system (Siegler & Opfer 2003). Recent evidence suggests that rapid and broad adoption of linear representations can be induced in situ by providing feedback on a few key numbers (Opfer & Siegler, 2007). In this paper we develop and implement a Bayesian inferential procedure to detect and facilitate representational change in numerical estimation. The proposed procedure of an adaptive numerical experiment both infers a learner's representation and predicts the feedback that is most likely to induce representational change. In the feedback session, in particular, we optimize the effectiveness of feedback stimuli by maximizing the discrepancy between the currently inferred model of representation and the target model (e.g., straight linear line). We provide an application of this procedure using simulated subjects and demonstrate its effectiveness in inferring representational state and inducing change.

Monday, 9:20 (Session C)

The 2-CUSUM Process Model for Two-Choice Reaction Time: An Information-Discounting and Memory-Forgetting Model. Yajun Mei, *Georgia Institute of Technology* . In this talk, spurred by the two-choice experiments in which the subject does not know the time of occurrence of the signal, we extend Ratcliffs diffusion model to the 2-CUSUM process model by emphasizing natural connections to the sequential change-point detection problems in statistics. Unlike existing sequential sampling models which are based on Wiener, Ornstein-Uhlenbeck, or Poison processes, the proposed 2-CUSUM process model utilizes another family of widely used stochastic processes: the regulated or reflected Brownian motions. There are two main new features in the proposed 2-CUSUM process model: information discounting in the sense of subtracting a non-negative term to Brownian motions (or Wiener processes) in the cumulative information processes, and memory forgetting in the sense that the decision makers will forget or ignore those "not so significant" information that is not consistent with their prior knowledge, and will start afresh to cumulative information until there is sufficient evident to prove that their prior knowledge information is incorrect. Surprisingly, Ratcliff's diffusion model turns out to be a special case of the proposed 2-CUSUM process model when the information discounting rate is zero. However, if the information discounting rate is positive, their properties can be completely different. For example, from the asymptotic viewpoint, the reaction time of Ratcliff's diffusion model is distributed according to a mixture of Gaussian distributions, whereas that of the proposed 2-CUSUM process model is a mixture of Gaussian and exponential distributions. Directions for further research are also discussed.

Sunday, 11:30 (Session C)

Probability judgments and partition dependence under sample space indeterminacy. Michael Smithson, *The Australian National University*, Jay Verkuilen, *City University of New York*, Tsuyoshi Hatori, *Tokyo Institute of Technology*, Michael Gurr, *The*

Australian National University . We extend the study of partition priming effects to settings in which the sample space is ambiguous. Our experimental paradigm presents judges with k alternatives but no indication of whether the alternatives exhaust the space. A prime induces some judges to interpret the space as having a k-fold partition whereas others interpret the partition as more than k-fold. The resulting sums of each judges probabilities are modeled by a finite mixture of a beta distribution and one or more degenerate distributions. This model handles predictors in each of three submodels (location and dispersion of the non-degenerate distribution, and mixture composition). The model is fitted to real data from experiments, using maximum likelihood methods for independent observations and MCMC methods for dependent observations.

Monday, 16:20 (Session C)

A statistical mechanics treatment of children's learning process to write Arabic numerals. Rafael Hurtado, Carlos Quimbay, *Universidad Nacional de Colombia*, Mariela Orozco-Hormaza, Diego Guerrero, *Universisdad del Valle*, Alex Santos, *Universidad Nacional de Colombia* . We use results from cognitive psychology and statistical mechanics to develop a mathematical model for childrens learning process of three-digit Arabic numerals. The experimental setup consisted in asking 51 children in first grade of elementary school to write down in Arabic format a set of 36 dictated numbers. The same set of numbers ordered randomly was dictated in three sessions with two months of difference between consecutive sessions. Children production was classified from the syntactic structure of written numerals by using a cognitive model based on a semantic-lexical internal number representation. This model proposes sum and product structures as the main relationships between numerical concepts (Power, R. J. D., & Dal Martello, M. F. (1990). The dictation of Italian numerals. Language and Cognitive Processes, 5, 237-254). We model the social system as constituted by the set of written numerals and with an energy-like conserved quantity related to the syntactic structure of written numerals. We use the canonical ensemble to state that the probability distribution of the syntactic structure of the written numerals follows a Gibbs-Boltzmann distribution and to derive analytical expressions for thermodynamic quantities that describe the macroscopic state of the system. The empiric distributions for the syntactic structure of written numerals obtained in the three sessions fit to Gibbs-Boltzmann distribution with coefficient of determination R-Squared 0.9651, 0.9959 and 0.9807. We find for the three sessions that Gibbs entropy, temperature and internal energy decrease over time while Helmholtz free energy increases linearly.

Sunday, 11:50 (Session B)

Assessment Rate in Sequential Risky Decision Making. Avishai Wershbale, Timothy Pleskac, *Michigan State University* . Current cognitive models of sequential risky decision making tasks generally assume the same response process occurs at every opportunity (Wallsten et. al., 2005, Busemeyer & Stout, 2002). For example, during the Balloon Analogue Risk Task (BART), participants pump a computerized balloon and earn money for each successful pump, but gain no money if the balloon pops. The BARTs cognitive model posits a response process where at each and every pump opportunity/decision point; participants account for the distance from a target and base their response (pump or stop) off of an assessment of this distance. Response time data, however, suggests the existence of multiple response processes. A slow goal directed response, consistent with the original model, but also a fast routinized response selection process. Task exposure, as well as distance from the targeted pump, affects the rate at which assessments are made, with task exposure decreasing the rate of slow goal-directed responses and target distance increasing the rate. These results motivate the development of alternative process models of the BART. Maximum likelihood model comparisons suggest the best model assumes a dynamic trial dependant assessment rate. More generally, the idea that not every risky decision that is made is necessarily pre-

ceded by a goal directed assessment is similar to vicarious trial and error rates that occur in rats during maze learning (Tolman, 1948). The multiple response processes may also help explain known differences in BART performance that were found between conduct disorder adolescents and their control group counterparts (Crowley et. al., 2006).

Tuesday, 15:20 (Session B)

The convolution operation for associative memory: (nearly) found in the brain. Jeremy Caplan, *University of Alberta* . Two mathematical frameworks can explain a broad range of human memory behaviour: Matrix models (Anderson, 1970) use matrix multiplication to store associations, whereas "holographic" models (Westlake, 1970; Borsellino and Poggio, 1971) use convolution. Matrix multiplication has been thought of as neurally plausible due to its similarity to learning in connectionist networks and being viewed as plausibly carried out by the circuitry within the hippocampus; this has been used to push convolution-based models on the back burner as neurally implausible (Pike, 1984). A recent surprising finding - "grid cells" in medial entorhinal cortex (Hafting et al., 2005), a major input to the hippocampus - appear to form a 2D spatial Fourier basis set for a place representation thought to be held within the hippocampus (Solstad et al., 2006). Fourier transform is a well known mathematical shortcut to compute convolutions in $O(n \log(n))$ (Brigham, 1974). I suggest that the grid-cell finding tells us that the hippocampus carries out spatial, as well as non-spatial associative learning via convolution (in addition to - or conceivably instead of - matrix multiplication), supporting the neural plausibility of convolution-based memory models and potentially explaining how the hippocampus implements associative symmetry (Bunsey and Eichenbaum, 1996), a property of convolution-based models wherein there is no directionality stored within associations (Asch and Ebenholtz, 1962). This insight suggests that hippocampal modelers may need to consider convolution as a computational function of the hippocampal-entorhinal pathway, and may help explain the pattern of association-memory impairments in medial temporal lobe amnesia.

Tuesday, 11:30 (Session B)

Binarizing Multi-link Multinomial Processing Tree (MMPT) models. Xiangen Hu, *The University of Memphis*, William Batchelder, *University of California, Irvine* . Multi-link multinomial processing tree (MMPT) models parameterize rooted trees by assigning manifest categories to the leaves and parameter vectors to the non-terminal nodes of the tree. In particular if a non-terminal node has $u > 2$ children, then the parameter vector assigned to the node will have u component parameters that are non-negative and add to one. The special case where every non-terminal node has exactly two children leads to the class of binary MPT (BMPT) models, which is well understood mathematically and statistically. This paper will present some formal results that connect MMPT and BMPT models. We will show that for any MMPT there is an associated set of BMPT models each of which is statistically equivalent to the MMPT model. We call this collection of such models a 'binarization' of the MMPT model. An obvious advantage of a binarization is that it allows us to utilized existing theory and implementations for BMPT models. We will focus on the following mathematical and statistical questions regarding binarization: 1) How to construct a general binarization algorithm? 2) How to use binarization to improve statistical analysis? For example, given a set of parameters of interest in an MMPT model, how to obtain a binarization that contains only the selected parameters (hence ignoring other parameters), 3) How to understand the mathematical structure of the set of 'minimal binarizations' of a given MMPT with respect to a set of parameters.

Tuesday, 9:40 (Session C)

Comparing Three Different Equations Representing Utility for a Single Reinforcement Schedule. Robin Gane-McCalla, *Dare Institute* . Counting trial time and applying p to a sequence of trials, produces a game theoretical/economic

equation of utility (Von Neumann & Morgenstern, 1944). Commons, Woodford & Trudeau (1991) proposed a second way to examine utility, which will be called the Quantitative Analysis of Behavior Equation. It is applied to a single t reinforcement schedule (Schoenfeld & Cole, 1972). This latter schedule and equation application may be considered as intermediate between the Game Theoretical/Economic Model and Herrnstein's (1970) Matching Law applied to variable interval schedules. The matching law is: $R_1 = kr_1/r_1 + r_e$, where R_1 = rate of response, r_1 is the rate of reinforcement, and r_e is reinforcement besides r_1. We assume rate R_1 is a behavioral measure of utility. We show all three equations are essentially the same when applied to the t-schedule. For our t-schedule, $v_i = p(v_i) * v_d$, where v_i = effective or perceived reinforcer value at time i, $v_{d\cdot}$ = value with a given delay Under the Commons et al equation, given a sample with 4 cycles of length 2 secs, a pigeon receives a reinforcer with $p = .25$, or $p = .75$, the p being similar to the probability of a reinforcer in the traditional utility case. With the addition of trial time, and multiple trials, the utility equation was similar to the Commons et al value equation because the values add after being discounted appropriate to their time away from choice. Likewise the matching law equation and the Commons et al equation support that the key variable is the rate of reinforcement.

Sunday, 16:20 (Session C)

Model Equivalence between the Diffusion Model and the LCA. Don van Ravenzwaaij, Han van der Maas, Eric-Jan Wagenmakers, *University of Amsterdam* . In their influential Psychological Review paper, Bogacz, Brown, Moehlis, Holmes, and Cohen (2006) used phase planes to investigate the conditions under which the diffusion model (Ratcliff, 1978) and the leaky, competing accumulator model (Usher & McClelland, 2001) may be mathematically equivalent. In this study, we extend their findings and identify two challenges. First, the model equivalence implies that boundary separation in the diffusion model changes from trial to trial, which is inconsistent with the assumptions of the diffusion model. Second, we show by simulation that model equivalence only holds for boundary separation values unlikely to occur in practice.

Tuesday, 16:20 (Session A)

A Dynamic Model for the Emergence of Two-sided Social Conflicts. Seth Marvel, Jon Kleinberg, Robert Kleinberg, Steven Strogatz, *Cornell* . When seized by certain types of social conflict, human communities show a remarkable tendency to divide into two camps. This phenomenon can be observed in the competition among political parties, standard-setting in the marketplace, and the outbreak of international war. We consider here a nonlinear system $\mathrm{d}X/\mathrm{d}t = X^2$ (where X is a square matrix) that exhibits this general behavior—for generic initial conditions, it sorts itself into two factions over time. This system also has a natural interpretation in terms of human psychology: its form can be qualitatively justified using social balance theory. On the empirical end, we find that the system gives results consistent with various previously studied cases of social fission, for example Zachary's karate club division and the World War II Allies/Axis division. On the theoretical end, we prove a collection of mathematical results that together help explain how the two-way splitting process occurs over the course of the idealized dynamics. Included in these results is a procedure for predicting the membership of the two sides without integrating $\mathrm{d}X/\mathrm{d}t = X^2$, and a characterization of the expected time-dependent evolution of the system in the large-population limit.

ACCEPTED POSTERS

Sunday, 17:00 (Poster Session)

The Predictability and Abstractness of Language: A Study in Understanding and Usage of the English Language through Probabilistic Modeling and Frequency. Revanth Kosaraju, *The Harker school* . Accounts of language acquisition differ significantly in their treatment of the role of prediction in language learning. In particular, nativist accounts

posit that probabilistic learning about words and word sequences has little to do with how children come to use language. We examined the accuracy of this claim by testing whether distributional probabilities and frequency contributed to how well 3-4 year olds were able to repeat simple word chunks. Corresponding chunks were the same length, expressed similar content, and were all grammatically acceptable, yet the results of our study showed marked differences in performance when overall distributional frequency varied. We found that a distributional model of language predicted our empirical findings better than a number of other models, replicating earlier findings and showing that children attend to distributional probabilities in an adult corpus. This suggested that language is more prediction-and-error based, rather than on abstract rules which nativist camps suggest.

Sunday, 17:00 (Poster Session)
An ANS-Based Model of Children's Small-Set Size Judgments. James Negen, Barbara Sarnecka, *University of California, Irvine* . Before learning how to use counting effectively, young children first learn the meaning of the first four number words (e.g., Wynn, 1992). We present a model of how children in this developmental period respond when you ask them to estimate how many items are in a picture. This model assumes that children use the Approximate Number System (ANS), which is a cognitive system that provides a non-verbal estimate of the number of items in a given stimulus (for review, see Feigenson, Dehaene, & Spelke, 2004). The model infers the distribution of latent continuous activation intensities in the child's ANS from the distribution of discrete verbal responses. We present several ways in which this provides a good fit to data; as our focus, we show that scalar variability (the standard deviation of answers growing linearly with the mean), which is a well-known signature of the ANS, can be inferred from a large corpus of child data. This evidence speaks against the claim that the ANS is not used in early number-word learning (Le Corre & Carey, 2007).

Sunday, 17:00 (Poster Session)
Predicting behavior from genetics with correspondence analysis. Derek Beaton, Hervé Abdi, *The University of Texas at Dallas* . A recent important trend in cognitive neuroscience studies integrate behavioral and genomic data. For genomics, a popular approach identifies, in DNA, loci of variation, which are called single nucleotide polymorphisms (SNPs). Traditionally, in cognitive neuroscience studies, behavioral data are collected with questionnaires and psychometric instruments. Both behavioral and genomic data possess comparable structural properties. First, these data are organized by blocks, (e.g., chromosomes for a genome; memory or perception for behavior). Second, these data often have observations (i.e. subjects) that can be grouped based on criteria such as clinical diagnosis or familial relationship. Interestingly, each of these structures (genomics and behavior) can be analyzed with Multi-block Correspondence Analysis (MuCA) and Multi-block Discriminant Correspondence Analysis (MuDiCA) that are recently developed variations of correspondence analysis (CA), which in turn, is an eigen-decomposition technique for analyzing qualitative data. MuCA projects blocks or tables (i.e. genomic and behavioral data) in the same factor space, while MuDiCA creates a factor space to discriminate groups (i.e. clinical groups or families). Additionally, we want to reveal common and predictive information between genomics and behavior. This is achieved by adapting Partial Least Squares Regression for CA. Furthermore, MuCA and MuDiCA incorporate an inferential component, through cross-validation techniques such as jackknifing, bootstrapping and permutation tests, which can be used to develop and refine hypotheses about cognitive, behavioral and genetic development. We present CA, MuCA and MuDiCA and illustrate them with an example integrating genomics (SNPs) and behavioral data (neuropsychological and neuroimaging).

Sunday, 17:00 (Poster Session)
Mathematical Modeling of Memory Evolution - Pure Decay. Eva Cadez, Evan Heit, *University of California, Merced*, Vladimir

Cadez, *Astronomical Observatory Belgrade, Serbia* . Memory processes possess properties of a physical dynamic system and can be qualitatively described by a suitable set of differential equations. In this work, we analyze analytical results of a specific mathematical model that simulates a time dependent processing of a memory pattern of a person. The memorized pattern evolves in time which can be qualitatively described by a single first order differential equation typical of non-uniform damping and attenuation processes found in physics. Such an equation is solved analytically for various mathematical expressions for the initial pattern, simulating lists of objects memorized i.e. learned, and for model functions for the attenuation rates. The attenuation rate modifies decay of memory without rehearsal. We show that it can simulate the object and time dependent individual attention or an influence of task instructions warning about false memories in paradigms involving process of memorizing patterns. The obtained solutions are discussed and plotted in a normalized form that shows a time variation of relative ordering of memorized objects, which may represent their subjective significance. The significance is simulated and discussed in terms of findings about familiarity and temporal phenomena in list recall experiments. Current literature is not clear on roles of pure decay of memory partially because it is extremely hard to isolate it from processes which are postulated to have similar role in forgetting. We hope this view of its dynamics, with simulations of existing data, may help clarify the concept and aid research on decay.

Sunday, 17:00 (Poster Session)
Model-mechanisms for effects of item-on association-memory in paired-associate learning. Christopher Madan, Jeremy Caplan, *University of Alberta* . Paired-associate (PA) learning paradigms are extremely common in memory research; however, memory behaviour in these paradigms relies on both memory for items and for their pairings. Several mathematical modeling frameworks have been applied successfully to PA empirical phenomena. However, our new behavioural results demand that these memory models be derived further, in order to identify loci within the major models where item-level versus association-level effects could materialize. Here we present a systematic approach to modeling item- versus association-memory effects in PA learning, with a specific focus on comparing the Matrix Model and TODAM, and using BSB to model redintegration effects. These derivations and simulations suggest a range of model-relevant effects that item properties could have, some of which are suggestive of existing empirical results and others of which may foreshadow future findings.

Sunday, 17:00 (Poster Session)
What Can the Diffusion Model Tell Us About Prospective Memory? Sebastian Horn, Ute Bayen, *Heinrich-Heine-Universitaet Duesseldorf*, Rebekah Smith, *The University of Texas at San Antonio* . Prospective memory (PM) involves remembering to perform intended actions in the future (i.e., "remembering to remember") and often occurs in the midst of other ongoing tasks. Ongoing task performance can be negatively affected by an additional PM task. This cost- or interference effect of PM is observed on non-target trials, even before the first opportunity to perform the intended actions. Surprisingly little is known about the specific reasons for these cost effects. In addition, extant analyses with ongoing lexical decision tasks were usually restricted to RTs of correct word trials. We extend this approach by applying Ratcliff's diffusion model in the PM paradigm to examine the processing components underlying cost effects and their relation to PM performance. The model-based results suggest that non-decisional RT components and criterion shifts explain a substantial proportion of the change in ongoing task performance and can thereby inform current theories of PM.

Sunday, 17:00 (Poster Session)
The Wisdom of the Crowd Playing the Price is Right. Michael Lee, Shunan Zhang, Jenny Shi, *University of California Irvine* . In the "Price is Right" game show, players compete to win a prize, by placing bids on its

price. We ask whether it is possible to achieve a Wisdom of the Crowds effect, by combining the bids to produce an aggregate price estimate that is superior to the estimates of individual players. Using data from the actual game show, we show that a Wisdom of Crowds is possible, especially by using models of the decision-making processes involved in bidding. The key insight is that, because of the competitive nature of the game, what people bid is not necessarily the same as what they know, and better estimates are formed aggregating latent knowledge than observed bids. We discuss what our results say about studying competitive group decision-making. We finish by arguing our results also highlight the fundamental role models of cognition and decision-making should play in solving real-world problems typically approached only from the non-psychological perspectives offered by statistics and machine learning.

Sunday, 17:00 (Poster Session)
Detection of Rare Events and Categorization. Max Quinn, Holly Jimison, *OHSU*, Daphna Weinshall, *Hebrew University of Jerusalem*, Frank Ohl, *Leibniz Institute for Neurobiology*, Hynek Hermansky, *Dept. Electrical and Computer Engineerin*, Misha Pavel, *OHSU* . The detection of rare and novel events or stimuli, at the crux of many intelligent systems, has a long history in psychology, pattern recognition and machine learning. There are several interpretations of these notions that have surfaced recently in computational cognition and that have increasingly been incorporated into engineering systems. In this paper we will first review and contrast mathematical representations of three well-established versions of novelty detection: oddball detection, salience and surprise. Each will be described within a common framework involving probability distributions over input features, utility on outcomes, and low level models. We will then propose an interpretation of novelty in terms of incongruence. An example of an incongruent stimulus is a clearly heard but unknown word, which is related to the important task of out-of-vocabulary word detection. We will describe the detection of incongruent stimuli in terms of a general framework that represents categorization processes by humans and machines, and will then propose a mathematical formulation of the phenomenon. This general approach will be illustrated using several paradigms in human and machine classification.

Sunday, 17:00 (Poster Session)
Instruction determines the error pattern in relative order judgments. Yang Liu, Michelle Chan, Jeremy Caplan, *University of Alberta* . Judging the relative order of events is a core function of human memory. In short, (sub-span) consonant lists with immediate judgments of relative recency (JOR), instruction wording ("which item was presented earlier?" versus "which item was presented later?") appeared to reverse memory search direction (Chan et al., 2009). We wondered whether instruction wording would have an analogous influence on the JOR judgment in supra-span lists. However, supra-span lists are more complicated; both a recency effect and a distance effect are typically observed (e.g., Yntema & Trask, 1963). Participants performed JORs on sub-span and supra-span consonant lists (Experiment 1; LL = 4 ,8) or a range of supra-span noun lists (Experiment 2; LL = 4, 6, 8, 10). Linear mixed-effects analysis revealed a similar instruction effect on supraspan lists as for subspan lists, consisting of an increase in response time (RT) performance with increasing target position for the "Later" instruction and a decrease in RT performance with target position for the "Earlier" instruction. Importantly, instruction influenced the error-rate pattern for both subspan and supraspan JOR data. A version of SIMPLE model designed to explain serial recall data with the addition of a serial-position gradient (Brown et al. 2007) which we view as an implementation of an attentional bias explanation of the data fits the chief qualitative features of the data including the difference between instructions. Our findings and model fit suggest that the JOR task may be understood as a two-dimensional judgement, the second dimension reflecting a congruency-based bias across position.

Sunday, 17:00 (Poster Session)

Assessing psychometric functions and thresholds using unforced-choice adaptive methods. Kai-Chun Chang, Yung-Fong Hsu, *National Taiwan U.* . One of the long-standing interests in psychophysics is the study of thresholds for discriminability. While threshold theories (e.g., Luce, 1963) embrace the concept of (discrete-state) thresholds, signal detection theory (Green & Swets, 1966) discounts such a concept. Until very recently, the meaning of thresholds was still not fully understood (see Rouder & Morey, 2009). We are concerned with the practical issue of estimating threshold values. In doing so, we find it necessary to clarify the concept germane to the psychometric function, which is customarily constructed using psychophysical methods with a binary-response format. We then argue that confidence responses are also important for the construction of psychometric functions and the estimate of thresholds. We outline an algorithm to incorporate confidence responses into a family of (non-parametric) adaptive methods for threshold estimation. Typical examples are the three-category weighted up-down (WUD) method proposed by Kaernbach (2001) and the four-category WUD suggested by Klein (2001). We argue that such a rating-scale response algorithm can be further extended to the continuous version, for which a response algorithm called "visual analogue scale" can be applied.

Sunday, 17:00 (Poster Session)

An Extension of the Categorical Invariance Model to Continuous Domains. Ronaldo Vigo, *Ohio University*, John Kruschke, *Indiana University* . The categorical invariance model (CIM) developed by Vigo (2008, 2009a, 2009b, 2009c), has been successful in predicting the degree of subjective difficulty experienced by humans when learning concepts defined by Boolean rules. The CIM introduces the concept of a logical manifold for measuring the degree of structural homogeneity of a Boolean category. The CIM posits that the structural complexity of a Boolean category is inversely proportional to its degree of invariance and directly proportional to its cardinality. In addition to making successful empirical predictions about the learning difficulty ordering of key Boolean categories involving discrete dimensions, we show here that the CIM is highly flexible in that it can be easily extended to continuous cases by generalizing the DNF (disjunctive normal form) description of the categorical stimulus to allow for continuous values in the real number interval $[0, 1]$. In this theoretical note, we use the cDNF (continuous DNF) of a concept function as defined in CFMS multi-valued logic (Cattaneo et al., 1993). This note also serves as an introduction to the CIM.

Sunday, 17:00 (Poster Session)

Applications of Shannon's Entropy Theorem to Psychology. Koralur Muniyappa Mahendra, *Airvana Networks India Pvt Ltd, India* . Applications of Shannon's Entropy Theorem to Psychology. Background Motive: Shannon's Entropy Theorem is proposed to measure how much uncertainty or information is associated with the occurrence of a probabilistic event. Since many of the stimulus (especially emotional stimuli) occurrence events are probabilistic in nature or are not certain events which make the Shannon's Entropy Theorem easily applicable to general-behavior prediction. Methodology/Model: Shannon's Entropy Theorem states that the entropy H of an experiment with n number of outcomes is given by the formula $H = K\sum[p(i)log(1/p(i)]$; i= 1 to n; K=constant. From above we obtain the expression for the amount of uncertainty (I) associated with the occurrence of each outcome of the experiment as below $I = Klog(1/p)$; The term I corresponds to probabilistic-component of the response given by the brain to the stimulus with probability of occurrence p. Hence the total response (R) is equal to the sum of probabilistic-component (I) and normal-component (N). $R = I + N$; N=normal-response to the stimulus treating it as certain event. The above conceptualizations been utilized to explain below and many more. 1) Maximization Principle: How to optimize the efficiency of the all human/animal activity together minimizing the cost involved.

2) Defining abstract terminology in field of psychology. 3) Explain Audience psychology when he listens to a song or story/incident or watches a movie 4) Proving "There is no end to Human desires". 5) Explains important and standard emotional/social behavior.

Sunday, 17:00 (Poster Session)

Cognitive Modeling Repository. Jay Myung, Mark Pitt, Daniel Cavagnaro, *Ohio State University* . Quantitative modeling has contributed substantially to the advancement of the cognitive sciences. Papers introducing and testing cognitive models regularly appear in the top journals. The growth and success of cognitive modeling demonstrate why modeling itself should be a primary quantitative method in the researcher's toolbox. Yet this method of scientific investigation remains underutilized by the research community at large, in part because of the hassles in obtaining data sets to model and the difficulties in implementing models. The goal of this project is to assist scientists in their cognitive modeling efforts by creating an online repository containing data sets that can be modeled and the cognitive models themselves. The current state of the project and future plans will be presented. Prior to the conference, the work-in-progress repository website (www.cmr.osu.edu) will be opened up to conference attendees for their comments and feedback. The project is funded by the Mathematical Modeling of Cognition and Decision program of the Air Force Office of Scientific Research.

Sunday, 17:00 (Poster Session)

Modeling the Time Course of Interference. Annika Boldt, *Humboldt-Universität zu Berlin*, Roger Ratcliff, *Ohio State University*, Eric-Jan Wagenmakers, *University of Amsterdam* . In the Stroop task and the Simon task, irrelevant information interferes with the processing of the relevant stimulus attributes, causing an increase in response times and error rates. One popular method for studying the temporal dynamics of these interference effects is to manipulate the extent to which the irrelevant information gets a head start. In a seminal study, Kornblum, Requin, Whipple, & Stevens (1999) manipulated the temporal delay (stimulus onset asynchrony or SOA) that separates the presentation of irrelevant from relevant information. The results showed that the time course of the interference effect differs between the Stroop and the Simon task. These and other results appear to put great constraints on how mathematical models account for interference in the Stroop and Simon task. For instance, Stafford & Gurney (2007) pointed out that the diffusion model cannot handle empirical data from interference tasks when SOA is very long. Here we seek to replicate the findings of Kornblum et al. (1999) while including a very long SOA condition. Moreover, we have implemented Kornblum's computational model and compare its ability to describe the data to different extensions of the drift diffusion model. We conclude that developing and testing mathematical models to conflict data can advance our understanding of the underlying mechanisms of interference.

Sunday, 17:00 (Poster Session)

Bow Effects in Absolute Identification. Pennie Dodds, Chris Donkin, *Indiana University*, Scott Brown, Andrew Heathcote, *The University of Newcastle* . The bow effect is one of the key phenomena observed within absolute identification. Normally characterised by poor performance for stimuli in the centre of the set relative to the surrounding stimuli, the bow effect is so named as it forms a U shaped curve when plotting stimuli against performance. We demonstrate that this bow effect can be distorted when using a within-subjects manipulation of the number of stimuli making up the set, leading to an atypical W-shaped bow effect. This W effect is characterised by improved performance for stimuli in the middle of the set relative to their surrounding stimuli. We show that this effect is caused by the additional presentations of centre stimuli which arise naturally from a within-subjects manipulation of set size, and that the effect is not simply the result of response biases. These findings strongly suggest that a within subjects manipulation of set size is inappropriate for absolute identification tasks, and that theo-

ries of absolute identification must account for stimulus-specific, long-term improvement due to additional presentation frequency.

Sunday, 17:00 (Poster Session)
Functional Principal Component Analysis and the Capacity Coefficient. Devin Burns, Joseph Houpt, James Townsend, *Indiana University* . The capacity coefficient is a well established measure of the efficiency of processing combined sources of information. It has been applied to measure cognitive processes ranging from audio-visual integration to face perception. Recently, the capacity coefficient has also been applied in various clinical situations. Typical clinical analysis, such as structural equation modeling, use scalar values or vectors with limited length as input. We explored the use of functional principal component analysis (fPCA) to allow researchers to describe the capacity coefficient, a continuous function of time, with a small set of discrete values. The fPCA approach was compared with two simple alternatives for reducing the capacity coefficient to a single value. We found that fPCA captured the major trends in the data more effectively than other methods.

Sunday, 17:00 (Poster Session)
Response dynamics and the time course of risky decision making. Joseph Johnson, Gregory Koop, Evan Bristow, *Miami University of Ohio* . Process-tracing techniques such as mouse- and eye-tracking have become popular for drawing inferences about the information acquisition process in decision-making–but not necessarily the dynamic mapping of that information onto a response (utilization). Rather, even these very studies continue to treat responses discretely. In contrast, we propose that closer examination of the time course of the response process can yield new insights. The current work draws upon a growing body of research in cognitive science focusing on "action dynamics" (Dale, Kehoe, & Spivey, 2007; McKinstry, Dale, & Spivey, 2008; Spivey & Dale, 2006). This research has shown quite clearly that mental processing dynamics can be revealed in the associated continuous motor response. We present an analysis of the response trajectories (mousepaths) from participants in risky decision making tasks while moving from a neutral region to screen regions associated with the selection of various options. Even though participants were unaware that their mouse movements were being recorded (they were not explicitly tracking changes in preference), we see evidence of the implicit, competitive "pull" from foregone choice alternatives in the mousepaths towards chosen alternatives. We also find dependencies in the nature of these mousepaths on the risk of the chosen alternative, as well as changes occurring over repeated trials. We suggest how these novel metrics can provide new insight into the cognitive processes underlying decision making.

Sunday, 17:00 (Poster Session)
Assessing perceptual correlations in the uncertainty paradigm: Exploring predictions of decision models within the multidimensional signal detection framework. Robin Thomas, Ryan Brunton, *Miami University* . The uncertainty paradigm has been used in vision research to evaluate whether stimulus components are processed independently or not. In typical applications of this paradigm, a mutlicomponent stimulus differs in one of its components from a standard value and the observer needs to decide if the change is an increment or decrement. In the certainty condition, the observer knows which component will contain the change; in the uncertainty condition, the component that differs from standard is unknown. Performance across the two conditions can be compared to that which is predicted by independence of components. We derive predictions for observer sensitivity in the uncertainty condition and a relative measure, root-mean-square (RMS) that incorporates both uncertainty and certainty performance for three major decision models when using a signal detection theory framework stimulus components are perceptually correlated: a distance-classifier, the optimal decision model (ideal observer), and a decisionally separable (independent decisions) strategy. Data from an identification task and the uncertainty paradigm (using the same stimulus components)

are analyzed from the perspective of these theoretical results and model-fitting to assess the validity of the predictions.

Sunday, 17:00 (Poster Session)
"Hot Cognition" is Not Beyond the Reach of Formal Models: Higher-Dimensional Nonlinear Bifurcations Depict Psychological Stress and Coping. Lawrence Levy, *University of Western Ontario*, Weiguang Yao, *Med. Physics, Sudbury Hosp./Laurentian U*, George McGuire, *University College of Fraser Valley*, Daniel Vollick, *U. British Columbia/Okanogan*, Richard Neufeld, *U. Western Ontario* . A long-held canon of psychological stress and coping is that they are quintessentially dynamical and transactional, entailing reciprocal control and feedback mechanisms. The mechanisms incorporate coping activity, stressor level, and collateral variables such as subjective appraisal of coping effectiveness.Focusing on a prominent form of coping known as "decisional control" – positioning oneself in a multifaceted stressing situation so as to minimize the probability of an untoward event – established observations on stress-coping relations are expressed in the form of a 6-dimensional nonlinear dynamical equation. Analytical and numerical analyses disclose rich dynamical properties of the resulting system, with bifurcations from stable and unstable fixed-point equilibria (higher-dimensional saddle node), through limit-cycle repetitions, to chaos. Each attracting pattern corresponds with meaningful stress-coping relations. Stable equilibria take the form of elevated efficiency of decisional-control related cognition, combined with correspondingly low prevailing stressor levels, the opposite combination characterizing unstable equilibria. Substantively anchored local analysis discloses a Hopf-bifurcation structure that points to potential control of the parameter boundary where the systems' fixed-point equilibria lose or re-attain stability. Results inaugurate formal-model support for a pivotal assumption about this domain of human behavior, that intricate nonlinear dynamics embodied in theoretical physical systems in principle extend to higher-dimensional theoretical stress-coping systems.

Sunday, 17:00 (Poster Session)
How is Story Line Dependent Context Represented in the Brain? An investigation using EEG and MUBBADA. Mary Kathryn Reagor, Anjali Krishnan, James Jerger, Joseph Dunlop, Hervé Abdi, *University of Texas at Dallas* . In everyday life, we have many conversations (narratives) with different people at different times and places. How do we associate the information from these narratives? We must package it somehow because usually, once we remember one or two details, the rest seems to come flooding back into memory. Previous studies have shown that semantic relations can be used to prime a target word, but what about context? Here, we were interested in whether context alone facilitates word recognition. EEG was recorded while participants listened to stories and were then presented a series of words. We wanted to know if a word from one of the stories primed the recognition of the next word if it was also from that story (positive priming). Conversely, negative priming might occur if the next word was from another story, making it more difficult to recognize. To analyze the EEG data, we used a new multivariate method, Multi-Block Barycentric Discriminant Analysis (MUBBADA). MUBBADA has been designed to handle data with many more variables than observations, and is therefore well suited for EEG. The goal of MUBBADA is to predict group membership (condition) of observations and determine the discriminant contribution of blocks of variables (e.g. electrodes). MUBBADA gives factorial maps where the observations and categories are represented as points with confidence intervals. Using MUBBADA we can determine: 1) whether robust differences exist between negative and positive priming conditions, and 2) which electrodes contribute to the discrimination.

Sunday, 17:00 (Poster Session)
Wisdom of the Crowds Effects in Prediction of Future Outcomes; A case study using Fantasy Football Rankings. Timothy Rubin, Michael Lee, Mindy DeY-

oung, Mark Steyvers, *UC Irvine* . There exists a large literature demonstrating the "Wisdom of the Crowd" effect in aggregating across large numbers of individual estimates. Broadly, the explanation underlying this phenomenon is that individuals have access to some representation of the true value of what they are predicting, and that averaging across individual's estimates will remove the independent errors that are introduced when generating each prediction. We consider an alternative situation, in which individuals must make predictions for future events. Specifically, we evaluate whether we can generate accurate predictions for the performance of individual players in the National Football League (NFL) by aggregating across many individual predictions. We show that these aggregate predictions perform among the best individual human predictions, particularly when we consider performance across multiple sets of rankings. This research provides an interesting alternative to traditional Wisdom of the Crowd experiments, because there exists no ground truth at the time of prediction. An additional contribution of this work is that is illustrates how to extend models for aggregating individual rankings under conditions in which data is missing not at random (MNAR).

Sunday, 17:00 (Poster Session)
Bayesian Hierarchical Model Evaluation for the Receiver Operating Characteristic in Recognition Memory. Kenneth Olson, Trisha Van Zandt, *The Ohio State University* . One of the major tools for analyzing recognition memory is the receiver operating characteristic (ROC), which is a curve giving the probability of a hit (correct "old" response) as a function of the probability of a false alarm (incorrect "old" response). Signal-detection theory (Green and Swets, 1966) has been widely endorsed, not only because the shape of the ROC curves it produces are almost always consistent with data, but also because it provides a useful framework for describing the old/new decision. Recent debate (e.g., Wixted, 2007) has questioned whether the unequal-variance signal-detection model or a dual-process model (Yonelinas, 1994) better explains recognition data. The latter assumes that recognition decisions are based on recollection and familiarity, while the former assumes decisions are based on a single dimension of memory strength. Several authors (e.g., Pratte, Rouder, & Morey, 2010) have been using hierarchical models, fit by Markov chain Monte Carlo methods, to explore sources of variance in recognition tasks. However, no one has yet addressed the issue of model identifiability and flexibility using these methods. We examined the extent to which single and dual-process models could be distinguished in a series of simulations and fits of Bayesian hierarchical models. Our results have implications for the kind of data that can discriminate between the models and the practicality of using ROC curves as a basis for model selection.

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We ask that the last presenter in each session act as chair, and keep time for the session.

Time	Sunday, Queen Marie (A)	Sunday, Gevurtz (B)	Sunday, Fireside (C)
9:00	**Vandekerckhove:** A cognitive psychometrical model for speeded semantic categorization decisions	**Cavagnaro:** Adaptive Design Optimization for Testing Generalized Utility Theories	**Regenwetter:** Quantitative Testing of Decision Theories: I. Probabilistic Specification
9:20	**Ratcliff:** Modeling the Psychomotor Vigilance Test for Evaluating Sleep Deprivation	**Tang:** Adaptive Optimal Inference and Feedback for Numerical Representational Change	**Zwilling:** Quantitative Testing of Decision Theories: II. Empirical Testing
9:40	**Criss:** Using the diffusion model to discriminate between memory models	**Rho:** Adaptive Strategy Choice in Cognitive Diagnosis: An Application to Fraction Subtraction	**Popova:** Concensus among Concensus Methods
10:00	**Idrobo:** Application of the Ratcliff Diffusion Model to Reaction Times in a Two-Choice Auditory Detection Task	**Yurovsky:** Linking Learning to Looking: Model Selection for Eye Movements	**Petrov:** Symmetry-Based Methodology for Decision-Rule Identification in Same-Different Experiments
10:20		***coffee break***	
10:50	**Dutilh:** Practice decomposed: stimulus specific versus task specific effects	**Brown:** Towards a unified account of decisions from experience and description	**Luce:** Subjective Loudness As A Ratio Scale Function of Both Intensity And Frequency
11:10	**Ho:** Combining fMRI and the LBA model to ascertain a supramodal accumulator in perceptual decision making	**Scheibehenne:** How many tools to include into an adaptive toolbox? A Bayesian approach	**Dzhafarov:** A Criterion and Tests for Selective Probabilistic Causality
11:30	**White:** Developing and testing RT models for new paradigms	**Pleskac:** Judgment Field Theory: A computational model of subjective probabilities	**Smithson:** Probability judgments and partition dependence under sample space indeterminacy
11:50	**Simen:** Reward maximization, drift-diffusion and inter-response times in instrumental conditioning	**Wershbale:** Assessment Rate in Sequential Risky Decision Making	**Narens:** A new probability theory for belief and decision
12:10	**Donkin:** Diffusion versus Linear Ballistic Accumulation: Different Models for Response Time, Same Conclusions about Psychological Mechanisms?	**Yechiam:** The effect of losses on maximization: Loss aversion versus a global-effect model	**Perry:** Matching Regularity for 2D Shapes and Locations
12:30		***lunch break (jmp meeting)***	
13:45		**Larry Maloney:** Movement Planning under Risk, Decision Making under Risk	
14:45		***coffee break***	
15:20	**Batchelder:** Cultural Consensus Theory	**Shi:** Veridical binocular perception of metric properties of 3D shapes	**Zand Scholten:** Questionnaire data are linear enough: Inferences about interactions based on polytomous items
15:40	**Merkle:** Hierarchical models for improving individuals' subjective probabilities	**Wang:** Human four-dimensional spatial judgments on hyper-volume	**Cheng:** Cognitive Modeling as Derived Measurement
16:00	**Vul:** Wisdom of the Crowd Within: Sampling in Human Cognition	**Kwon:** Human recovery of the shape of a 3D scene	**Zeigenfuse:** A Three-Parameter Item Response Model of Matching
16:20	**Greene:** Representing consensus and divergence in communities of Bayesian decision-makers	**Li:** A computational model of the recovery of a 3D scene from a single 2D camera image	**van Ravenzwaaij:** Model Equivalence between the Diffusion Model and the LCA
16:40	**Steyvers:** A Bayesian approach to aggregate knowledge: Comparing groups of independent and communicating individuals	**Sawada:** Any 2D image is consistent with a 3D symmetrical interpretation	
17:00		***poster session***	

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Time	Monday, Queen Marie (A)	Monday, Gevurtz (B)	Monday, Fireside (C)
9:00	**Huber:** Learning to Forget: An Interference Account of Cue-Independent Forgetting	**Darlow:** A Rational Model of Attitude Polarization	**Chechile:** Fundamental Properties of Reverse Hazard Functions
9:20	**Davelaar:** A REM model of retrieval-induced forgetting	**Denton:** Exploring Active Learning in a Bayesian Framework	**Mei:** The 2-CUSUM Process Model for Two-Choice Reaction Time: An Information-Discounting and Memory-Forgetting Model
9:40	**Criss:** Using cued recall to move beyond task specific models	**Merkle:** A multivariate hierarchical Bayesian model of confidence and accuracy in probabilistic category learning	**Houpt:** The Statistical Properties of the Survivor Interaction Contrast
10:00	**Howard:** A distributed representation of remembered time	**Love:** Looking to Learn, Learning to Look: Attention Emerges from Cost Sensitive Information Sampling	**Heathcote:** The Lognormal Race Model of Choice RT
10:20		***coffee break***	
10:50	**Nelson:** The SARKAE model: Experience with novel characters determines recognition memory. Pt I	**Pavel:** Computer-Based Assessment of Working Memory Using Computer Games	**Hawkins:** A particle filter account of multi-alternative decisions
11:10	**Shiffrin:** The SARKAE model: Experience with novel characters determines recognition memory. Pt II	**Jimison:** Computer-Based Assessment of Planning and Problem Solving	**Austerweil:** Feature learning as nonparametric Bayesian inference
11:30	**Polyn:** Extending the Context Maintenance and Retrieval model of free recall	**Ambert:** Toward a Cognitive Model of a Computer-Based Trail Making Test	**Lake:** Discovering Structure by Learning Sparse Graphs
11:50	**Dennis:** What is context?	**McKanna:** Generalized Assessment of Divided Attention Through Unobtrusive Monitoring of Computerized Tasks	**Turner:** Hierarchical Approximate Bayesian Computation
12:10	**Hemmer:** Estimating Individual Differences in a Rational Model of Memory		**Sanborn:** Learning of dimensional biases in human categorization
12:30		***lunch break (smp meeting)***	
13:45		**Mike Jordan:** Recent Developments in Nonparametric Bayesian Inference	
14:45		***coffee break***	
15:20	**von Helversen:** Averaging and Choosing in the Mind: Should Judgments Be Based on Exemplars, Rules or Both?	**Krishnan:** Distance-based Partial Least Squares Regression (DISPLS): A new approach to relate distances in psychology and neuroimaging	**Jameson:** Evolutionary models of color categorization based on realistic observer models and population heterogeneity
15:40	**Anders:** Rank-Aggregation and Consensus in Ballroom Competition	**Dunlop:** How to analyze multifactorial neuroimaging experimental designs with pattern classifiers	**Kaznatcheev:** Evolution and cognitive cost of ethnocentrism
16:00	**Zhang:** The Wisdom of Crowds in Solving Bandit Problems	**Golden:** Application of a Robust Differencing Variable (RDV) Technique to the Department of Veterans Affairs Learners' Perceptions Survey	**Sanderson:** Color charts, aesthetics, and subjective randomness
16:20	**Miller:** A Bayesian Analysis of the Wisdom of Crowds Within	**Stollhoff:** Measuring abnormality in neuropsychological deficits using generalized linear mixed models	**Hurtado:** A statistical mechanics treatment of children's learning process to write Arabic numerals
16:40	**Lee:** Cognitive Models, the Wisdom of Crowds, and Sports Predictions	**Addis:** Calculating Prediction Intervals for Future Performance	
17:00		***business meeting (followed by banquet)***	

We ask that the last presenter in each session act as chair, and keep time for the session.

Time	Tuesday, Queen Marie (A)	Tuesday, Gevurtz (B)	Tuesday, Fireside (C)
9:00	**Perfors:** New computational approaches to word learning	**DeCarlo:** On Incorporating Item Effects into Signal Detection Theory	
9:20	**Andrews:** Learning Word Meanings from Sequential and Syntactic Statistics	**Weidemann:** ROC analyses of confidence responses and reaction times in recognition memory	**Commons-Miller:** Can Perceived Value Be Explained by Schedules of Reinforcement?
9:40	**Piantadosi:** Beyond Boolean Logic: A learning theory for complex compositional concepts	**Pooley:** Modeling Multitrial Free Recall	**Gane-McCalla:** Comparing Three Different Equations Representing Utility for a Single Reinforcement Schedule
10:00	**Salakhutdinov:** One-Shot Learning with a Hierarchical Nonparametric Bayesian Model	**Prince:** The Contribution of Study-Test Lag to Old Item Variability in Recognition Memory	**Commons:** Does Hierarchical Complexity of Items Predict Synchrony Across Content and Gaps Between Stages?
10:20		***coffee break***	
10:50	**Frank:** Early word learning through communicative inference	**Nelson:** Modeling knowledge formation and frequency effects in lexical decision	**Fields:** Structure from Sequence: A Nonparametric Bayesian Analysis of Human Sequence Learning
11:10	**Feldman:** Using a developing lexicon to constrain phonetic category acquisition	**Cox:** Developing Knowledge and Probing Its Structure with Primed Lexical Decision	**Shanahan:** Mathematical Expectation of Threat, Unpredictability, and Mechanisms of Stochastic "Faint Threat" in a Model of Decisional Control
11:30	**Hills:** Semantic Associates in Motherese: Comparing the Associative Structure of Adult and Child-directed Speech with Graph Analysis	**Hu:** Binarizing Multi-link Multinomial Processing Tree (MMPT) models	**Wagenmakers:** Cortico-Striatal Connections Predict Control over Speed and Accuracy in Perceptual Decision Making
11:50	**Kachergis:** Modeling the Acquisition of the Mental Lexicon	**Batchelder:** A String Language for Multinomial Processing Tree Models	**Trueblood:** Explaining Order Effects. The Belief-Adjustment Model Versus The Quantum Inference Model
12:10	**Andrews:** A Hierarchical Logistic-Wald Model for the Analysis of Lexical-Decision Data	**Purdy:** Multinomial Processing Tree Models and Bayesian Networks: Some formal results	**Iverson:** Remarks on quantum cognition
12:30		***lunch break***	
13:45	**Thomas Griffiths:** Using Probabilistic Models of Cognition to Identify Human inductive Biases		
14:45		***coffee break***	
15:20	**Smith:** An Integrated System Analysis of Gain and Orienting Models of Attentional Selection	**Caplan:** The convolution operation for associative memory: (nearly) found in the brain	**Vigo:** A non-probabilistic measure of relational information based on Categorical Invariance Theory
15:40	**Shiffrin:** Guided Visual Search	**Shankar:** A distributed representation of internal time leads to scale invariant timing behavior	**Stringer:** A Bayesian model of judgment revisions in a social setting
16:00	**Hotaling:** Models of Information Integration in Perceptual Decision Making	**Bracis:** Rats, non-rewards, and decaying uncertainties	**Davis-Stober:** Changing Minds: Estimation of Multiple Preference States Via Normalized Maximum Likelihood
16:20	**Marvel:** A Dynamic Model for the Emergence of Two-sided Social Conflicts	**Schweickert:** Regularities in Dream Social Networks	**Lee:** Emergence of Cooperation between Intelligent Individuals with Personality
16:40			
17:00		***end of meeting***	

Poster Session

Kosaraju: The Predictability and Abstractness of Language: A Study in Understanding and Usage of the English Language through Probabilistic Modeling and Frequency

Cadez: Mathematical Modeling of Memory Evolution - Pure Decay

Shi: The Wisdom of the Crowd Playing the Price is Right

Chang: Assessing psychometric functions and thresholds using unforced-choice adaptive methods

Myung: Cognitive Modeling Repository

Houpt: Functional Principal Component Analysis and the Capacity Coefficient

Neufeld: "Hot Cognition" is Not Beyond the Reach of Formal Models: Higher-Dimensional Nonlinear Bifurcations Depict Psychological Stress and Coping

Olson: Bayesian Hierarchical Model Evaluation for the Receiver Operating Characteristic in Recognition Memory

Negen: An ANS-Based Model of Children's Small-Set Size Judgments

Madan: Model-mechanisms for effects of item- on association-memory in paired-associate learning

Quinn: Detection of Rare Events and Categorization

Vigo: An Extension of the Categorical Invariance Model to Continuous Domains

Boldt: Modeling the Time Course of Interference

Koop: Response dynamics and the time course of risky decision making

Reagor: How is Story Line Dependent Context Represented in the Brain? An investigation using EEG and MUBBADA

Beaton: Predicting behavior from genetics with correspondence analysis

Horn: What Can the Diffusion Model Tell Us About Prospective Memory?

Liu: Instruction determines the error pattern in relative order judgments

Muniyappa Mahendra: Applications of Shannon's Entropy Theorem to Psychology

Dodds: Bow Effects in Absolute Identification

Brunton: Assessing perceptual correlations in the uncertainty paradigm: Exploring predictions of decision models within the multidimensional signal detection framework

Rubin: Wisdom of the Crowds Effects in Prediction of Future Outcomes; A case study using Fantasy Football Rankings